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MAJOR MIDWEST SNOWSTORMS

EUGENE M. WEBER

THIRD WEATHER WING

OFFUTT AFB, NEBRASKA 68113

AUGUST 8, 1979

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3d Weather Wing

Offutt AFB, Nebraska 68113

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FOR THE COMMANDER

Daniel R Gornell

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Chief, Aerospace Sciences Division

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Trough Action	Prevailing High Pressure	Maritime Polar Frontal System	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This Technical Note discusses the various atmospheric conditions essential to the development of major wintertime storm systems over the Midwest (Central United States). Primary emphasis is placed upon determination of areas favorable for cyclogenesis. Intensification and movement of the 500mb low as a function of 500mb height falls tendency is presented. Identification, intensification, and movement of the main surface system is then introduced. Finally, the related developments at all levels of the atmosphere, as they occurred, are shown in various summary forms.

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PREFACE

Chief Master Sergeant Weber has continued to examine nearly all systems which produced significant snowfall over areas of the Midwest since 3 WW Technical Note 76-2 was published in 1976. This revision contains additional subjective rules which were not presented in original report. The summary in Chapter 6 has been expanded considerably. Many of the subjective rules presented throughout this report have been condensed into three single page summaries and may be used as a reference.

The information contained within the Technical Note gives forecasters information concerning those favorable phenomena that are required at various levels in the atmosphere well in advance of, just prior to, and during development of a major snowstorm. The presentation should be most helpful to forecasters in determining the intensification, movement, and the effects of major systems that pass through the Central U.S. during the winter months.

Forecasters at weather stations throughout the United States, particularly those located between the Rockies and the Appalachians, should find this study most beneficial. It has been written with the new forecaster in mind, because Chief Weber feels they are the ones needing it the most and having more to gain from it.

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LIST OF ILLUSTRATIONS

INTRODUCTION

This Technical Note contains an orderly discussion of the atmospheric conditions necessary for the development of major snow storms (those producing on the order of four inches or more of snowfall) over the central United States.

The presentation starts out at the 300mb level by explaining the ideal jet stream pattern preceding and accompanying storm development. At the 500mb level it focuses on identification of conditions and areas over the western half of the United States that are favorable for cyclogenesis. Related long and short wave trough actions at the 500mb level are also discussed. Then, using several actual occurrences, the correlation of height falls tendency to that of the newly formed 500mb low, including their related movement, is discussed. From there the discussion drops down to the 850mb level where the lee-side trough is discussed relative to proper identification and proper forecast of subsequent movement of the main surface feature. Then in Chapters 4 and 5, many examples of surface synoptic patterns that produced significant snowfalls over parts of the Midwest are presented.

After identifying areas and conditions favorable for storm development in Chapter 4, the discussion next keys on the identification, intensification, and steering of the main surface low in Chapter 5. The value of analyzing the 500mb height falls and maintaining continuity of the tendency of the height fall center, in addition to the 500mb low/trough impulse, is shown through numerous case studies. In the final chapter, summaries for recognizing heavy snowfall patterns using many of the subjective rules within the tech note will be shown. Finally, the 8-11 January 1975 Midwest blizzard is discussed. The related events at all levels are illustrated in 12-hour intervals from start to finish of the storm to tie the conditions at the various levels together.

CHAPTER 1

300 MB

INTRODUCTION

The orientation of the jet stream and the location and movement of isotach maxima along it are factors that provide good indications for development of significant storms over the western United States. In this chapter, the 300mb main jet stream patterns or configurations known to precede major storm development will be discussed. These patterns can be thought of as being characteristic of short wave and long wave situations, respectively. The relative locations of the jet stream patterns and the wind maxima moving along them, as they are significant to development in lower levels, will be presented.

300 MB JET ORIENTATION AND WIND SPEED MAXIMA

The movement of wind maxima along the jet stream should always be considered in assessing the potential for storm development. A maxima isotach area either moving southeasterly into or appearing within the bottom of a trough will usually cause the trough to deepen. A closed low circulation often appears at the 500mb level when the isotach maximum along the jet stream swings eastward into the bottom and/or southeast quadrant of the trough. The appearance of just such a closed low at 500mb and its location are extremely important for determining whether a major snowstorm will subsequently develop over the Midwest.

300 MB PATTERNS PRECEDING MAJOR SNOWSTORM DEVELOPMENT

The two most common 300mb jet patterns that indicate potential for storm development are shown in Figures 1 (short wave) and 2 (long wave). Each pattern is shown relative to the two significant periods in the development of a storm system. Figure a represents the jet stream configuration during the period of cyclogenesis over the western U.S., while figures b and c depicts the jet stream position later during the storm's progression across the Midwest. Wind maxima areas are also shown. The jet stream positions and the wind maxima depicted in Figures 1 and 2 are average patterns. Each jet stream/trough relationship will, of course, vary slightly from these patterns depending upon the strength of the jet. NOTE: The low center and troughing shown in each figure of this chapter is at the 500mb level.

SHORT WAVE PATTERN

Figure sequence 1 depicts a changing jet stream configuration within a deepening short wave trough. In Figure 1a, the short wave has moved inland from the Pacific Ocean or the Gulf of Alaska. The significant feature is the presence of a jet stream approaching the West Coast behind the trough. Generally, the overall pattern shown in Figure 1a is zonal with short waves (varying in intensity from nearly undiscernable to quite strong and evident) moving steadily eastward across the U.S. Storm development often occurs west of the Rocky Mountains with maximum storm intensification occurring over the central U.S. Cyclogenesis within the 500mb trough occurs just to the north of the area where the jet stream digs into the 300mb trough shown in Figure 1a. There are other factors besides the jet stream to be considered for 500mb low formation. These factors will be discussed in detail in Chapter 2.

In Figure 1b, the amplitude of the short wave continues to increase over the western U.S. Note the appearance of a wind maximum over Mexico and west Texas within the trough's base. Generally, the entire jet stream system will progress eastward with the short wave. There will be instances when a short wave trough moving eastward will appear to change into a long wave trough pattern[1] due to strong continued deepening of the system. This change of patterns can cause problems in determining the path of the low system across the Midwest. (See height fall center movements toward the south or southwest, Chapter 2, page 10).

1. **In discussing here and elsewhere in the technical note the intensification of short wave impulses, it will occasionally be implied that the short wave trough intensifies sufficiently to become a long wave trough pattern. The reader should not confuse this mention of the long wave trough pattern with the pattern of the mean long wave trough that is common at the upper levels over the northern hemisphere. The implication in this technical note is that an upper level flow can be zonal on day one only to change to a pattern (say on day three) having a strong trough extending from the Canadian Plains southward to Mexico.**

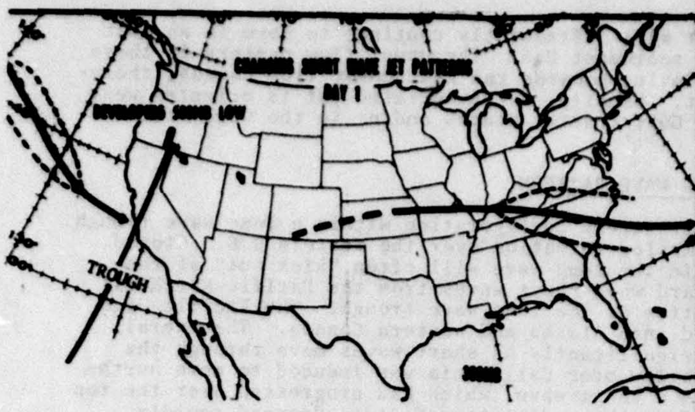

Figure 1a: Day 1

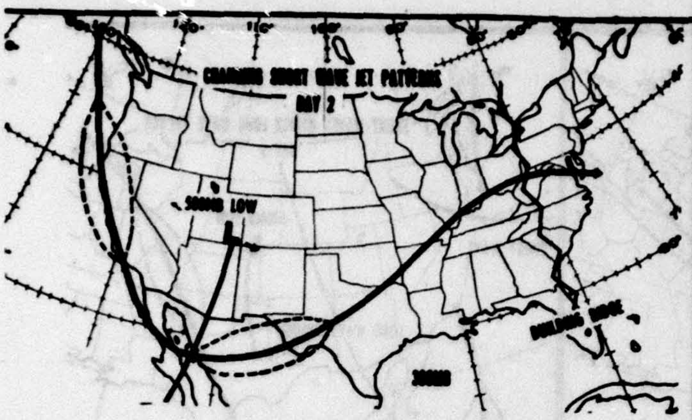

Figure 1b: Day 2

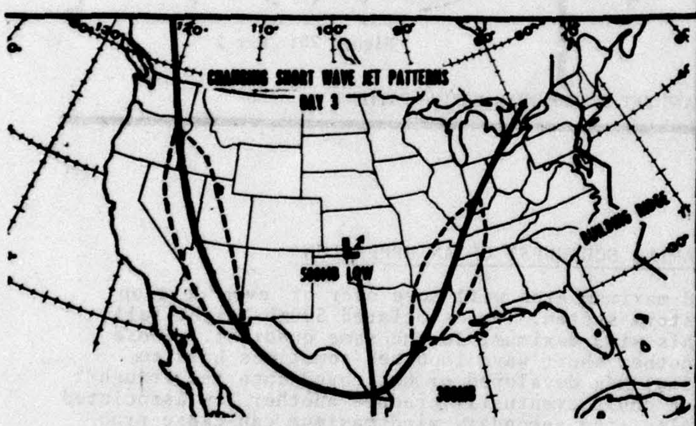

Figure 1c: Day 3

FIGURE 1: CHANGING SHORT WAVE JET PATTERN

The jet stream configuration shown in Figure 1c is typical with storm systems that organize over the western Plains-Rocky Mountain area. The wind maximum shown earlier within the trough's base (Figure 1b) has now swung northeastward and is located in the southeast quadrant of the trough. The jet stream should progress eastward as long as the system continues as a short wave feature. Quite often these short waves continue to intensify east of the Mississippi and take on the appearance of a long wave trough over the eastern U.S.

An important point to be considered in steering short wave lows eastward is that the jet stream axis is usually oriented WSW-ENE across the central and/or southern sections of the Midwest during storm development over the western U.S. A dangerous mistake can be made by continuing to steer the approaching 500mb low in an easterly direction along the jet's axis. As the trough reaches maximum amplitude (deepening) over the western U.S., the ridge usually present over the eastern U.S. also builds. The segment of the jet east of the low will swing northward and, in turn, will induce the storm system to track in a more northeasterly course. Short wave lows moving out of the Rockies often turn northeastward across the southern Plains; this feature will be discussed further in Chapter 2. For Midwest storms, the jet's eastern segment usually orients SW-NE to the east of the Mississippi River.

Lows moving into the Midwest will infrequently continue to move in an east to southeast direction towards the southeast U.S. The upper flow pattern in these cases would show a trough over or moving towards the East Coast from Canada, thereby precluding any ridge development. Usually, the associated jet is oriented west to east and further south over the Gulf coastal states and/or in the Gulf of Mexico.

LONG WAVE PATTERN

Figure 2a shows a typical jet stream configuration within a long wave trough. Such a pattern is conducive to 500mb low formation over the Western U.S. Closed lows and short waves embedded within the long wave will often "kick out" of the trough and move rapidly northeastward when short waves from the Pacific Northwest move southward and approach the bottom of the long wave trough. The Pacific High is pronounced and extends northward into Alaska and western Canada. The overall jet stream pattern doesn't change significantly as short waves move through the long wave. In Figure 2b, the 500mb low over California was induced to move northeastward over the central Plains as a short wave, which had progressed over the top of the Pacific ridge in the Gulf of Alaska and western Canada, dropped rapidly southward along the West Coast into the long wave trough.

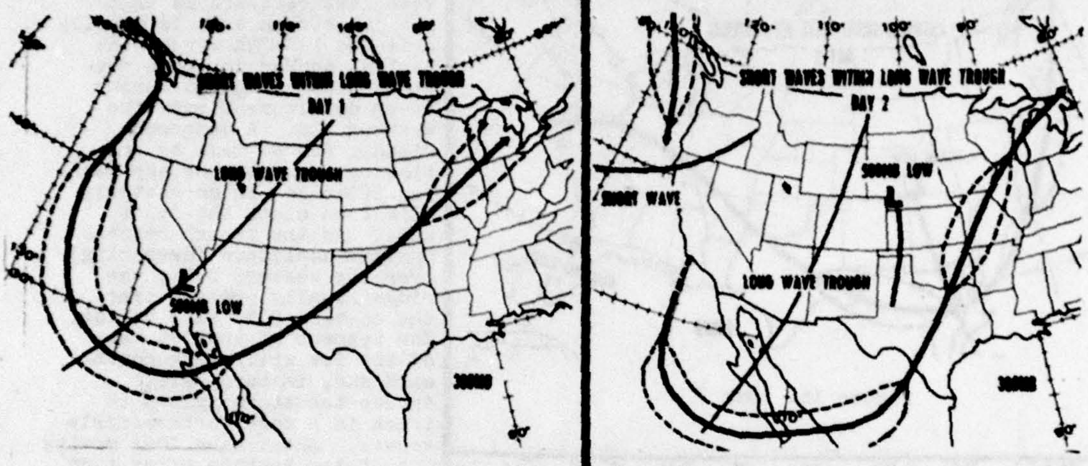

Figure 2a: Day 1

Figure 2b: Day 2

FIGURE 2: LONG WAVE JET STREAM/WIND MAXIMA PATTERN

WIND MAXIMA APPEARING SOUTHWEST OF AN UPPER LOW

Sometimes, a secondary wind maximum area will move over or even develop above the southwest quadrant of a storm system. An associated 500mb height fall area frequently develops, due to this wind maximum, in the same quadrant. These secondary wind maxima imply that another short wave impulse (sometimes hard to discern in the pressure and wind flow) has developed or has moved into the trough upstream from the low. This impulse could eventually produce another low associated with the secondary maximum area. Also, the secondary wind maximum can cause problems in determining the movement and the strength of the storm system located downstream over the Midwest. Figure 3 illustrates how an approaching wind maximum area (300mb) caused a storm system over Kansas to stall and begin filling.

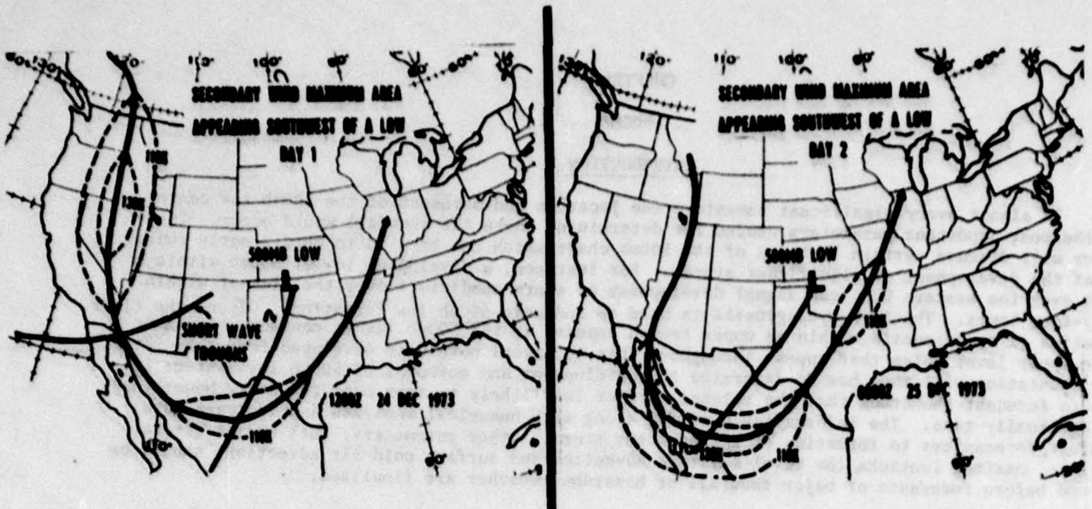

Figure 3a: 12Z 24 Dec 73

Figure 3b: 00Z 25 Dec 73

FIGURE 4: WIND MAXIMA SOUTHWEST OF UPPER LOW

The 500mb low over northwestern Oklahoma, shown in Figure 3a, developed in southern Utah, moved southeastward and began its northeasterly course over the Texas panhandle. Note that there is no wind maximum located near the low; however, a maximum does appear southwest of the system over Mexico and southern Texas. A strong 130+ knot jet maximum is moving southward across the western U.S. Note the short wave trough from Arizona to northern Baja California.

In Figure 3b, 12 hours later, the 500mb low still appears over the same area shown in Figure 3a. The primary 500mb trough retrograded over Texas as the new short wave moved into the bottom of the trough. Also, the 130+ knot wind maximum now appears within the trough's bottom. The effects of these two actions caused the entire low system over the southern plains to remain stationary for nearly 12 hours. The low began to move northeasterly when a 110-knot maximum developed along the jet over eastern Kansas and Texas as shown in Figure 3b. Twelve hours later, the 500mb low moved into eastern Nebraska with the 110+ knot wind maximum located over Missouri and Illinois. The 130+ knot maximum remained over Mexico and produced continued trough deepening. Subsequently, the 500mb short wave system appeared to have become a long wave trough feature. Short wave trough systems will often change into long wave systems when such secondary wind maxima appear upstream or within the trough's bottom as just presented in Figure 3. Wind maxima areas southwest of a low occur often within long wave troughs as short wave impulses move rapidly south from Alaska and Canada.

SUMMARY

The two major patterns of jet stream configurations that are typically associated with development of significant Midwest snowstorms were described. In the next chapter, significant patterns and changes evident at the 500mb level are discussed.

CHAPTER 2

500MB

INTRODUCTION

In almost every significant snowstorm the location and movement of the 500mb low center were the most important parameters needed for determining where the snowfall would occur. This Chapter will discuss certain features of the 500mb chart which can be used to obtain early awareness of the development of significant storms. For instance, a developing low at 500mb within a trough over the western U.S. can signal development of storm conditions over the Midwest within twenty-four hours. The term cyclogenesis is used to indicate 500mb low formation. Often, the first indication of cyclogenesis within an upper trough appears at the 500mb level; consequently, many of the upper level rules that appear throughout this technical note were developed from this level. The presentation will show how to determine the development and movement of 500mb low systems in order to forecast the track that the related surface low (likely to form over the Rocky Mountains) will eventually take. The information provided along with numerical analyses and forecast data can alert forecasters to formation of an impending storm. Other parameters, such as jet stream positions, maximum isotachs, low level moisture advection and surface cold air advection, should be examined before forecasts of major snowfall or hazardous weather are finalized.

LOW DEVELOPMENT

In many Midwest snowstorms, the initial indication of a threat appears within a deepening 500mb trough which has moved inland over the western United States or the Gulf of Alaska. As discussed in Chapter 1 and shown in Figure 1a, the location of cyclogenesis within these troughs varies from system to system and primarily depends on where the jet stream and maximum isotach area are digging into the trough. There are some middle level features that offer clues to probable cyclogenesis. Three features at the 500mb level (height fall centers, cold air advection, and weak contour/thermal gradients) are easily identified and should alert forecasters.

500MB HEIGHT FALLS

Considerable discussion pertaining to 500mb height fall areas and centers will be presented throughout this report. Investigation relating to the movement of the height fall center versus the main surface storm track, versus main low pressure development along stationary fronts, and versus the location of heavy snow areas are the basis of many subjective rules within this technical note.

A study correlation between the movement of the 500mb height fall center track and the movement of the main surface storm system track was started during the 1973-74 winter and continued over the next two winter seasons. The study revealed that a strong relationship existed between the height fall center track and the location of the heavy snowfall area within each storm system. The subjective methods from these investigations were then tried on selected major Midwestern snowstorms that occurred from 1952 to 1970, with successful results in nearly every case examined.

Height changes are plotted routinely on the NWS 500mb analysis. Locations of height fall areas and centers can be conveniently analyzed on the chart. Continuity of the fall center is very important and care should be taken in determining the center's position. Height fall centers usually have good continuity of movement and in nearly every instance the associated 500mb low will move reliably parallel to and north of these centers.

Weak contour and thermal gradients and cold air advection within the trough in conjunction with the associated height fall center are good indicators of probable cyclogenesis. Figure 4 shows a typical 500mb cyclogenesis pattern within a trough. In the many snowstorm cases studies, 500mb low development subsequently occurred north of the tighter contour and thermal gradients and the height fall center as indicated by the hatched area depicted in Figure 4. The developing 500mb low usually appears east to southeast of this hatched area 12 to 24 hours later, as shown in Figure 4, because the impulse is still moving southeasterly within the easterly moving trough.

Sometimes initial 500mb low formation occurs some distance to the north of this hatched area within the widest contour gradient area; however, this low will eventually dissipate and a new low will usually form just to the north of the associated height fall center and the tighter contour and thermal gradient area. An example of this will be covered in detail later in this chapter (Figure 12).

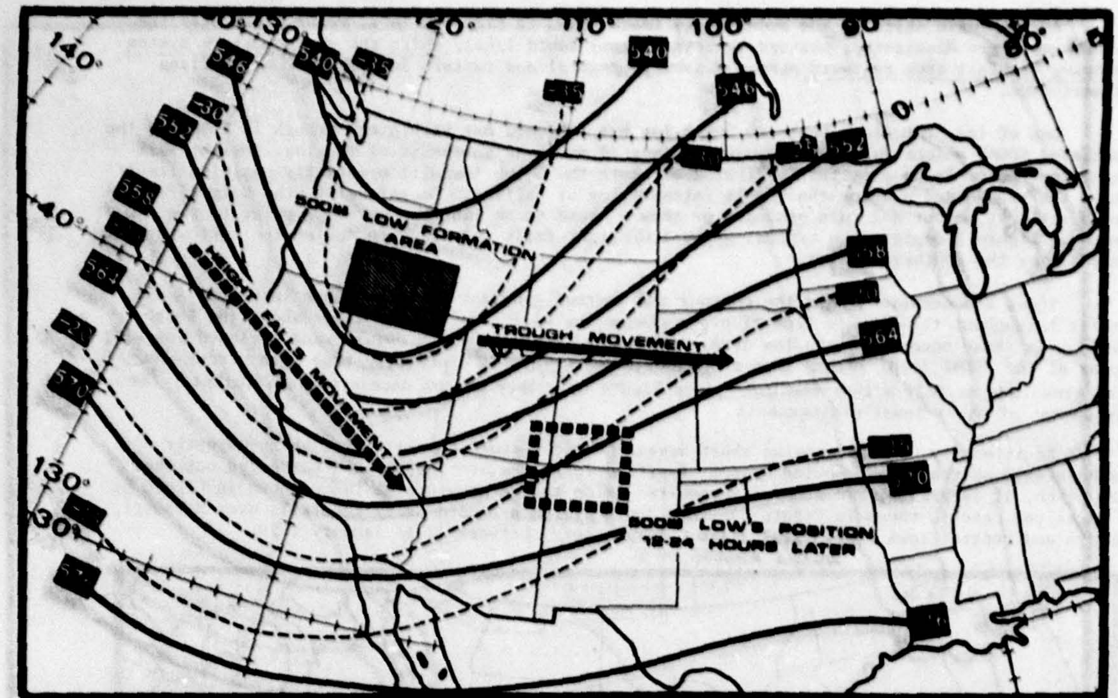

FIGURE 4: CYCLOGENESIS DEVELOPMENT WITHIN THE SHORT WAVE TROUGH

500MB LOW MOVEMENT

Lows that are developing within easterly moving short wave troughs over the western U.S. generally move in a southeast direction because of continued trough deepening and building of the Pacific ridge off the coastal areas of Canada and the U.S. Southeasterly movement continues until the low reaches the trough's bottom. The low then begins to turn eastward and, if a ridge is present or building over the eastern U.S., eventually turns northeastward. For sake of brevity, the term, "bottom out", will be used throughout the rest of this report to identify when the developing low has reached its lowest point within the trough, i.e., when the low or short wave feature terminates its southeasterly trajectory and begins to track east or northeast. For Great Plains snowstorms, the ideal area for lows to bottom out is over the panhandle region of western and northern Texas and central and western Oklahoma (Figure 5).

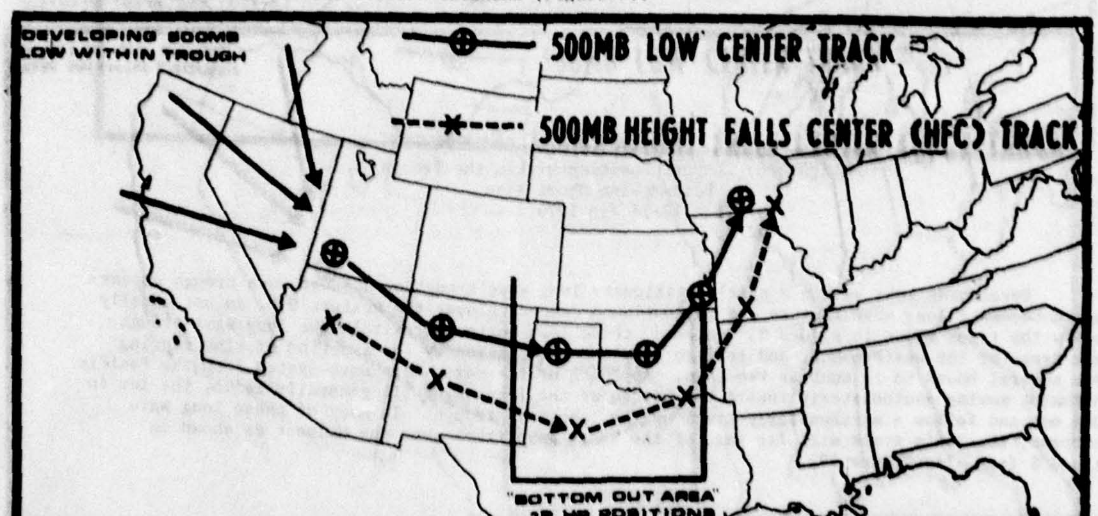

FIGURE 5: LOWEST POSITION WITHIN THE TROUGH

Any eastward shift of the recurvature track shown in Figure 5 (e.g. recurvature over the Arkansas-northern Mississippi-western Tennessee area) would likely shift the surface storm system and heavy snowfall area eastward across Missouri, central and eastern Iowa, Illinois, Indiana and northward.

One of the best clues that the 500mb low has bottomed out within the trough is found in the associated 500mb height fall center, usually located south or southeast of the low. Height fall center continuity is an excellent indicator of where the 500mb low will eventually position itself within the trough and whether the low is intensifying or filling. Occasionally, the height fall center will bottom out and turn eastward or show a trend to an easterly movement prior to the low turning. Figure 5 depicts the typical 500mb low/height falls relationship during the bottoming out process over the southern Plains.

There are occasions when the contour and thermal gradient patterns shown in Figure 4 will persist throughout the storm's life (i.e., a closed low will never appear at or above the 500mb level). In these occasions, the low develops from the lowest levels, upward, and a closed low will appear at the 700mb level rather than the 500mb level. This is especially true when strong short waves translate rapidly across the U.S. (see Figure 6). They do not decelerate sufficiently for development of upper level cyclogenesis.

Additionally, in fast-moving short waves, the recurvature tracks do not shift abruptly northeastward as the slower-moving systems typified in Figure 5. Instead, if bottoming out does take place, it is gradual and generally requires twice the recurvature distance shown in Figure 5. An excellent case is shown in Figure 6. This storm system produced heavy snowfalls over Missouri, eastern and central Iowa and Illinois (the Chicago storm) between 12-14 January 1979.

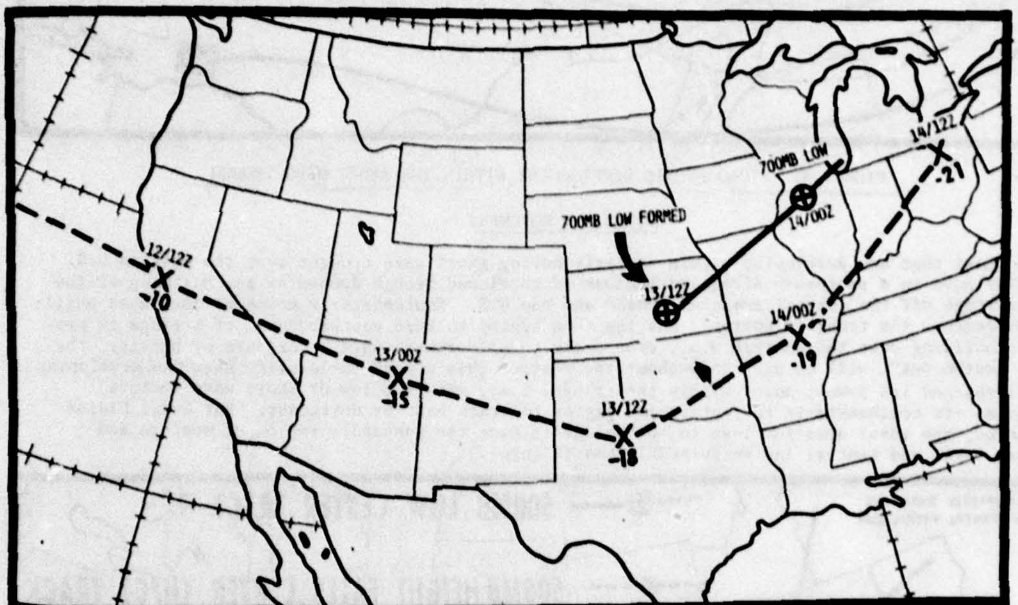

Figure 6: Lowest Position Within the Trough
Fast-Moving Short Wave
12-14 Jan 1979

Developing lows within a nearly stationary long wave trough or a short wave trough appearing to become a long wave feature due to continued deepening over the western U.S. do not usually follow the track shown in Figure 5. Instead, these lows bottom out within the long wave trough over areas of the western U.S. and tend to remain quasi-stationary for a period of time ranging from several hours to as much as two days. Approach of the next short wave system from the Pacific Northwest moving southeasterly toward the bottom of the long wave will generally induce the low to move out and follow a northeasterly track up the long wave trough. In many of these long wave patterns, the low's track will lie west of the short wave track over the Midwest as shown in Figure 5 (see also Figure 10).

Moderate height falls of ≥ 15 (> 150 meters) within a 12 hour period indicate that cyclogenesis has occurred or may occur shortly within the 500mb trough. Often, the height fall center will appear hours ahead of actual 500mb cyclogenesis. Generally, the height fall center moves inland over the West Coast with or slightly ahead of the trough. Cyclogenesis will appear to the north and usually within four degrees latitude of the height fall center 12 to 24 hours later. Figures 7, 8, and 9 illustrate the relationship between 500mb lows and height fall centers associated with the approaching short wave trough and during the storm's trek across the Midwest. The pressure and thermal analysis presented in each of the illustrations depicts the pattern of the last analysis received prior to low formation. Note the weak contour and thermal gradients and subsequent low development in each figure. The numerical value enclosed in parentheses below the height fall center, depicted by (X), is the largest height fall reported. From these three examples it can quite readily be seen that:

★ Height fall centers often move rapidly southeastward toward the base of the trough prior to and during low development and turn easterly when a decrease or no further increase in the magnitude of height fall center value occurs. The center will swing northeasterly if a ridge is present over the eastern U.S.

★ The 500mb low closely parallels and is always to the left of the track of the height fall center.

★ Though unrealistic to show in the illustrations; maximum height fall and low centers are always parallel and to the left of the jet stream. The height fall center never crosses the jet.

The following observations concerning the magnitude of height fall values are made based on four years (1972-1976) of snowstorm data:

★ The magnitude of height fall central values are usually at a maximum during the period when the related 500mb low is in the developmental stage (which generally takes place in the western U.S.).

★ The magnitude of height fall centers usually remain unchanged or will decrease while moving easterly within the bottom of the trough.

★ The magnitude of height fall centers again increases (sometimes considerably) while moving northeasterly. At this time the surface system should be approaching maximum intensification.

Additionally, in many of the cases reviewed, it has been found that the greatest distance between centers (500mb low and height falls) usually occurs during easterly movement through the base of the trough. The distance between the low and height fall centers will diminish thereafter as they move northeastward. Generally, the surface system is approaching maximum intensification and is usually in the occlusion stage by the time the two centers make their northeastward turn and begin to merge.

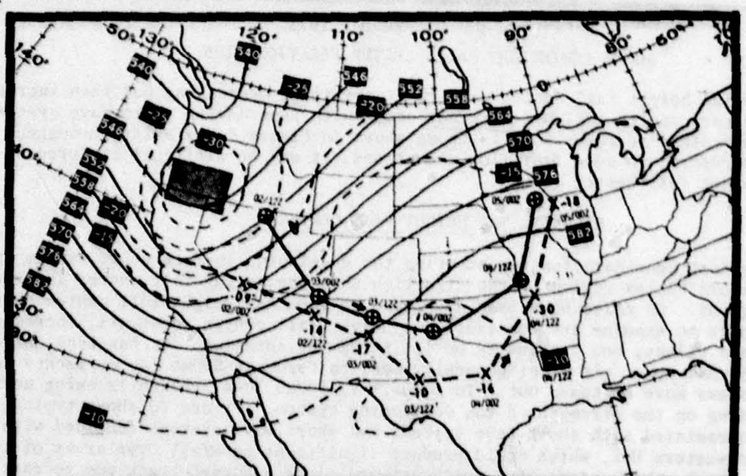

Figure 7: 2 - 5 Dec 1973

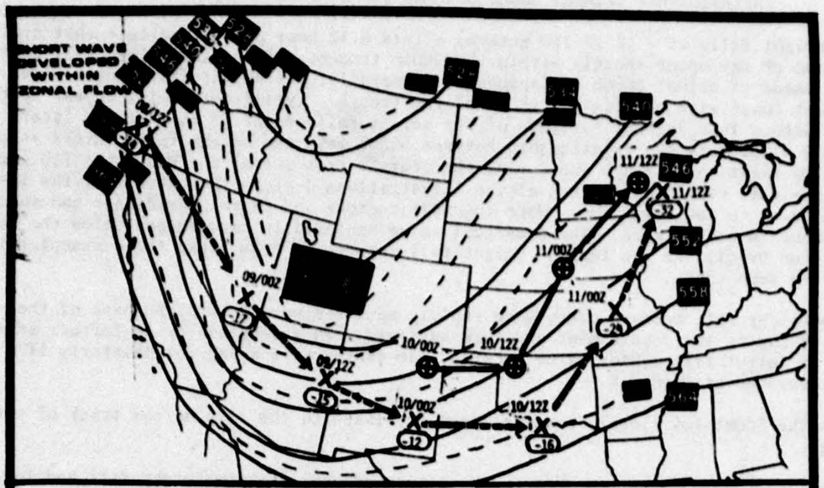

Figure 8: 8 - 11 Jan 1975

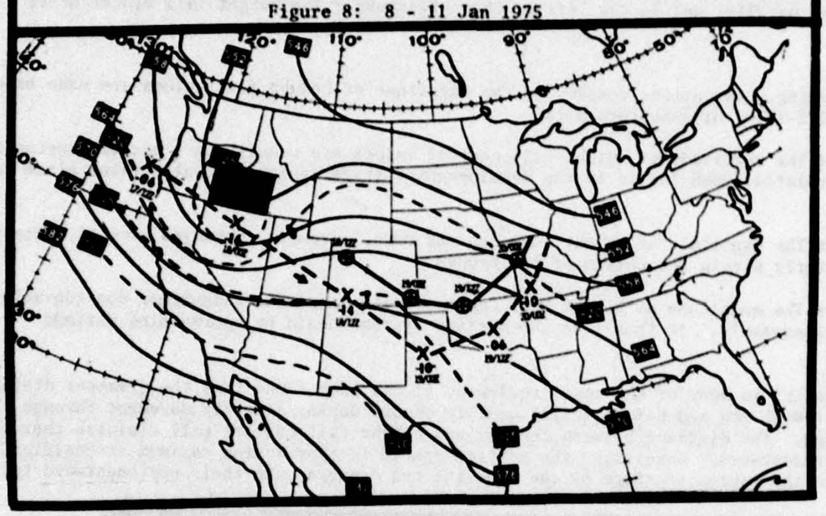

Figure 9: 18-20 Dec 1973

500MB LOW/HEIGHT FALLS CENTER RELATIONSHIPS

CAUTION: The sequential height fall center pattern (increasing, decreasing and then increasing again) across the western and central U.S. may not occur with fast-moving short wave systems (Figure 6) even though other features such as those shown in Figure 4 may exist throughout the snowfall period. Therefore, in some fast flow situations, it may be difficult to forecast recurvature using height fall center values.

STEERING THE HEIGHT FALL CENTERS

A very important consideration for steering the developing surface storm system over the Rocky Mountain - western Plains region is the direction that the height fall center is expected to take after bottoming out. No rules have been developed to forecast height fall center movements; however, the best tools to examine are continuity on height fall center movements, increase/decrease in central height fall values, and continuity on jet stream orientation. It has been noticed during research (1972-1976) that upper air progs generally tend to forecast 500mb low movements to the east once these systems have bottomed out. In actuality, 500mb lows frequently swing northeastward or northward, depending on the strength of the developing system. Figure 10 shows typical height fall center tracks associated with short wave systems and short wave systems embedded within a long wave trough over the western U.S. which could produce significant snowfall over areas of the central U.S. In Figure 10, short wave systems move northeastward along a curved track due to eastward trough movement and system deepening. Strong deepening indicated by large height falls would swing the system even further northward as indicated by the dashed track in Figure 10.

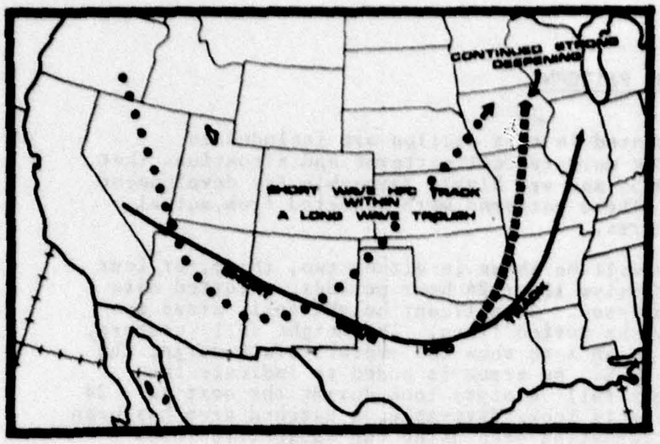

FIGURE 10
HEIGHT FALL CENTER TRACK - SHORT AND LONG WAVE

An example of height fall movement within a long wave trough is shown in Figure 10 as the dotted track. These centers usually bottom out over Arizona and New Mexico within the long wave and move up the trough as a short wave. The height fall center usually does not follow an actual curved track because there is little easterly movement of the short wave system due to the nearly stationary long wave trough. When the center bottoms out, it makes a rather abrupt turn. Most generally, after bottoming out, the height fall center will move in a nearly straight line towards the northeast. Probably the best method to forecast movement of the system is to project a straight line path in the direction of flow from the first analyzed height fall center reported on the 500mb analysis subsequent to bottoming out for the most likely course of movement.

HEIGHT FALL CENTER MOVEMENT TOWARDS THE SOUTH OR SOUTHWEST

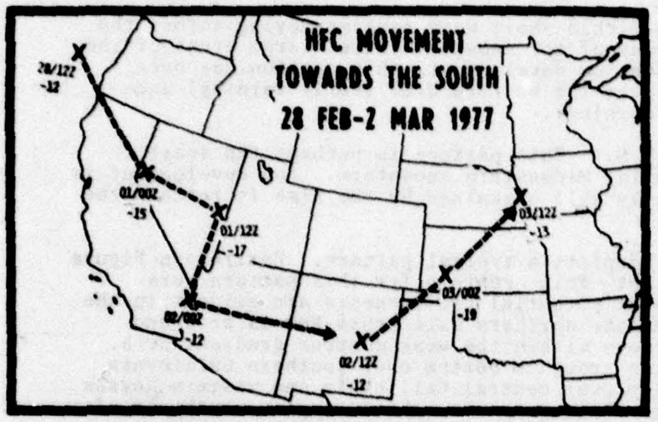

FIGURE 10A
EXAMPLE 1: 28 FEB-3 MAR 1977

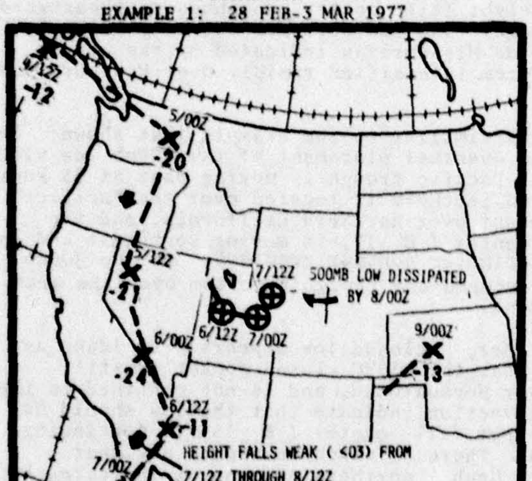

FIGURE 10B
EXAMPLE 2: 4 DEC-7 DEC 1978

Figures 7, 8 and 9 have illustrated that height fall centers generally move southeastward prior to bottoming out. Occasionally, height fall centers moving along a southeasterly track will abruptly turn south or southwest. This southerly turning indicates that the system is still strongly digging and, consequently, the storm's eastward movement would be delayed by several hours. A new surge of cold air within a short wave upstream (sometimes difficult to discern), along with other upper air changes can cause this southward shift of height fall centers.

Figure 10a and 10b depict two examples of height fall center movements in 12 hour periods. In Figure 10a note the abrupt shift southward as the height fall center dropped from southern Nevada to lower California. In Figure 10b, the height fall center moved southward from Washington to Arizona then shifted southwestward to northern Baja. Note in Figure 10b that the 500mb low did not persist and remain nearly stationary during its short life. The short wave that entered the Pacific Northwest continued to deepen (Figure 10b) and took on the appearance of a long wave feature 48 hours later. The primary clue that this trough system would not immediately eject and produce heavy snow over the Great Plains was the 7/00Z height fall center (-12) which appeared southwest of the previous center. Eventually (48 hours later), a short wave did eject and the related height fall center is shown over Oklahoma. Forecasters noting these changes will be a few hours ahead of the later numerical progs in forecasting the probable delay in the expected storm's arrival over the Midwest.

500MB PATTERNS

The 500mb trough patterns presented in this section are included to familiarize forecasters with some of the more typical patterns and situations that appear over the western third of the U.S. and are highly favorable for development of major snowstorms over the Midwest. These patterns were selected from actual occurrences of major Midwestern snowstorms.

Each upper air pattern example will be shown in either two, three, or four parts: Figures a, b, c, and d in successive 12 or 24 hour periods. Plotted data shown were extracted from NWS 500mb analyses. Significant height fall areas are analyzed on each analysis and are shown as dotted lines. The height fall centers, in 12 hour periods, are also depicted as an X to show the overall track during the storm's progression across the central U.S. An arrow is added to indicate the direction that the 500mb low (and height fall center) took during the next 12 - 24 hours. In those figures where cyclogenesis looks favorable, a hatched area has been included to indicate the probable low formation area using the subjective rules discussed earlier.

SHORT WAVE LOW DEVELOPMENT

Cyclogenesis occurs most often within short wave systems moving across the western U.S. and are responsible for many of the snowstorms over large areas of the Midwest. To further identify short wave low development, this section has been divided into two parts: Cyclogenesis over the Western U.S. (early warning) and cyclogenesis over the Rockies (little warning).

Cyclogenesis over the Western U.S. This pattern is perhaps the least difficult in which to forecast a potential Midwestern snowstorm. Low development is early and the upper low system is usually well organized by the time it reaches the Rockies.

Example 1 - Figure 11 depicts a typical pattern. Earlier in Figure 7, the tracks of the 500mb low and height fall centers for this pattern were presented. In Figure 11a, indications of potential cyclogenesis are evident in the weak contour and thermal gradients over the northern California-Nevada area and northward. Note the closed -30°C isotherm within the weak contour gradient area. An 80 knot max wind area has entered the trough's bottom over southern California and Nevada. Cyclogenesis should develop over central California and western Nevada within the hatched area shown in Figure 11a and the low should appear southeast of the hatched area within 12-24 hours. In Figure 11b, 24 hours later, a closed low appears over northeastern Arizona as the height fall center continues southeastward towards its lowest position within the trough. The low bottomed out near Lubbock, Texas (LBB), and turned northeasterly towards Missouri as indicated by the height fall centers in Figure 7. The surface system intensified rapidly over Missouri and became a major snowstorm.

Example 2 - This example is similiar to the example just shown; the main reason for presenting this case is the eventual placement of the 500mb low within the short wave trough. In Figure 12a, a Pacific trough is moving east at 35 knots. A strong cold air trough with a -30°C closed isotherm is located over the Pacific Northwest and weak contour gradient is present over northern California, and the Oregon-Washington area. The height fall center ($\geq$ -15) is moving southeast and is centered over southern Nevada north of the tighter contour gradient. At the 300mb level (not shown), a 110 knot jet max has entered the trough's bottom over the area of northern Baja, California to southern Arizona.

In Figure 12b, 12 hours later, a closed low appears over Idaho as the trough slows down to 20 knots. Note that the -30°C closed pocket is still persisting, has moved southeasterly to lower Nevada-Utah, and is not confined to the low. Weak contour gradient and cold air advection indicate that the low should be over this area and not over Idaho. The height fall center ($\geq$ -15) is continuing southeast at 20 knots over central Arizona. There is strong evidence now that cyclogenesis should occur over the southern Utah - northern Arizona as indicated by the hatched area in Figure 12b.

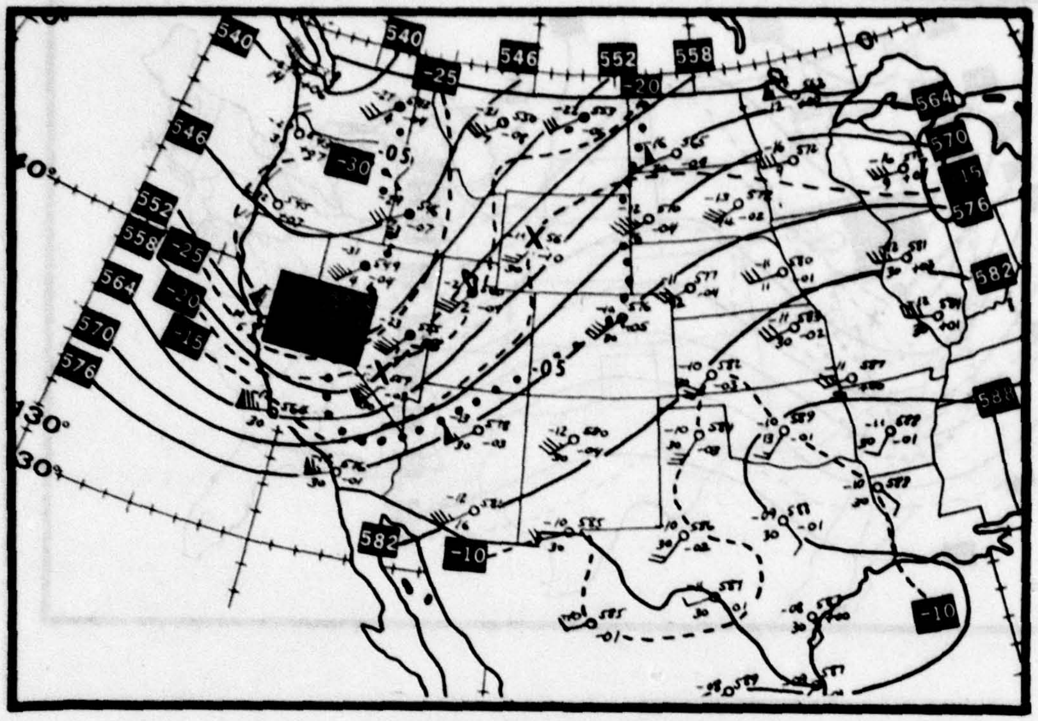

Figure 11a: 00Z 2 Dec 1973

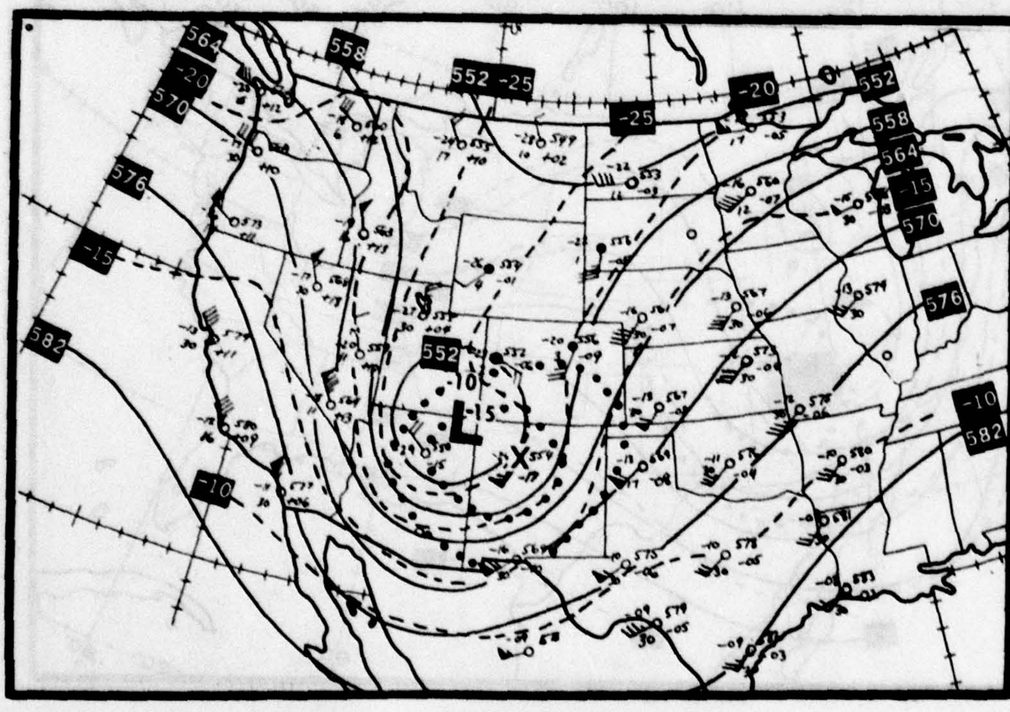

Figure 11b: 00Z 3 Dec 1973

FIGURE 11: EXAMPLE 1 - SHORT WAVE CYCLOGENESIS, WESTERN U.S.

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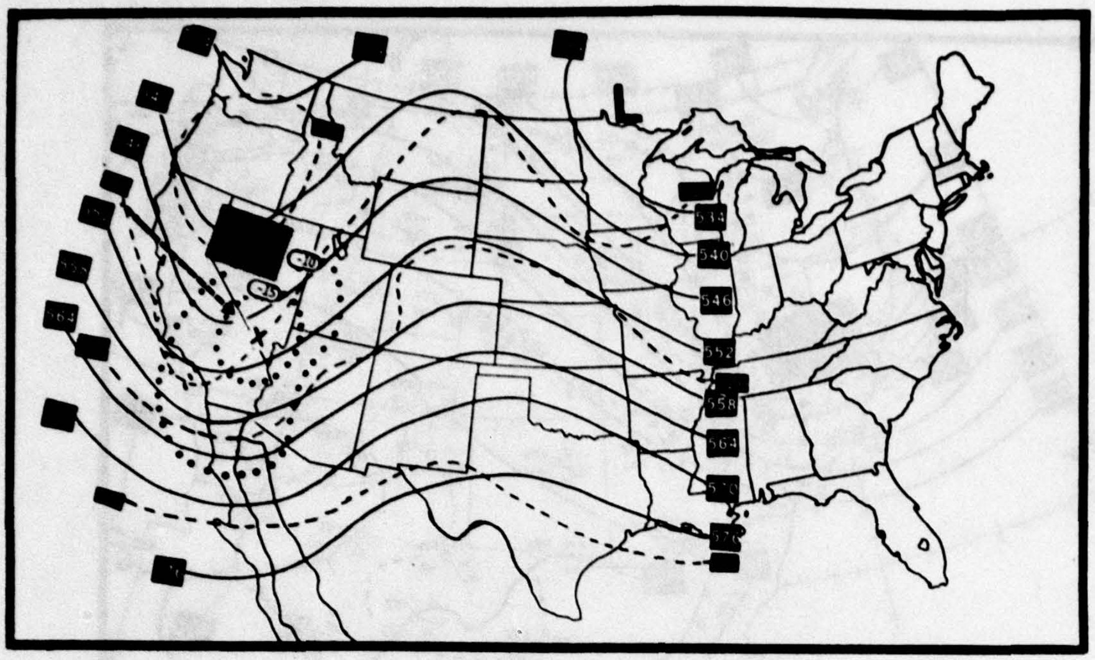


Figure 12a: 12Z 19 Jan 73

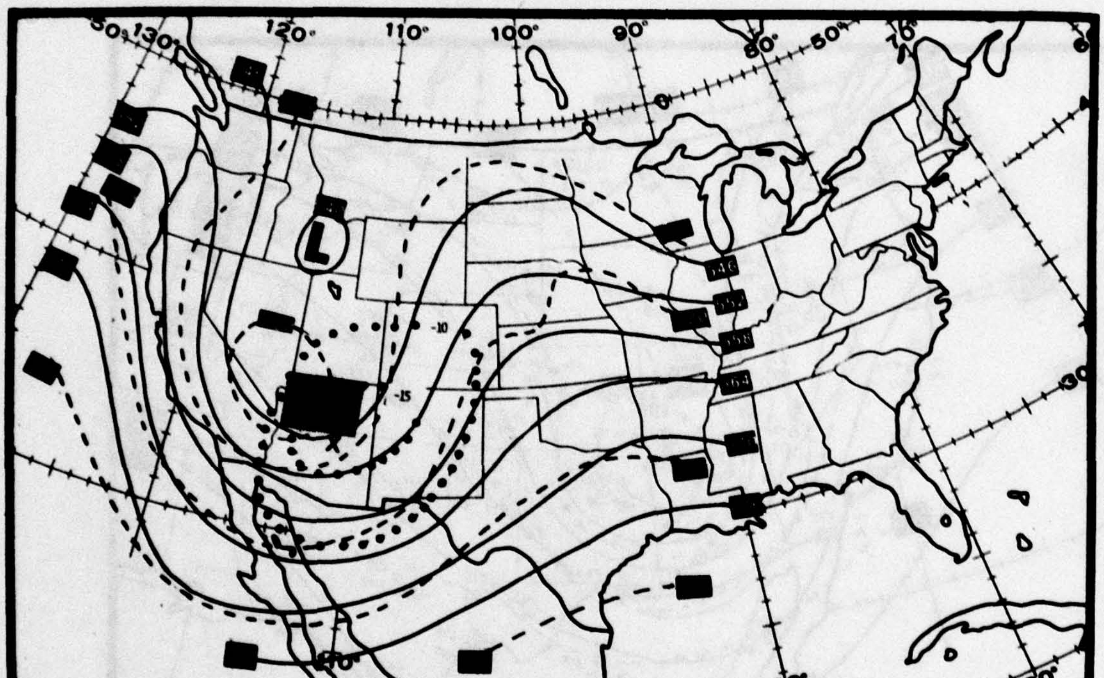


Figure 12b: 00Z 20 Jan 73

FIGURE 12: EXAMPLES 2 - SHORT WAVE CYCLOGENESIS, WESTERN U.S.

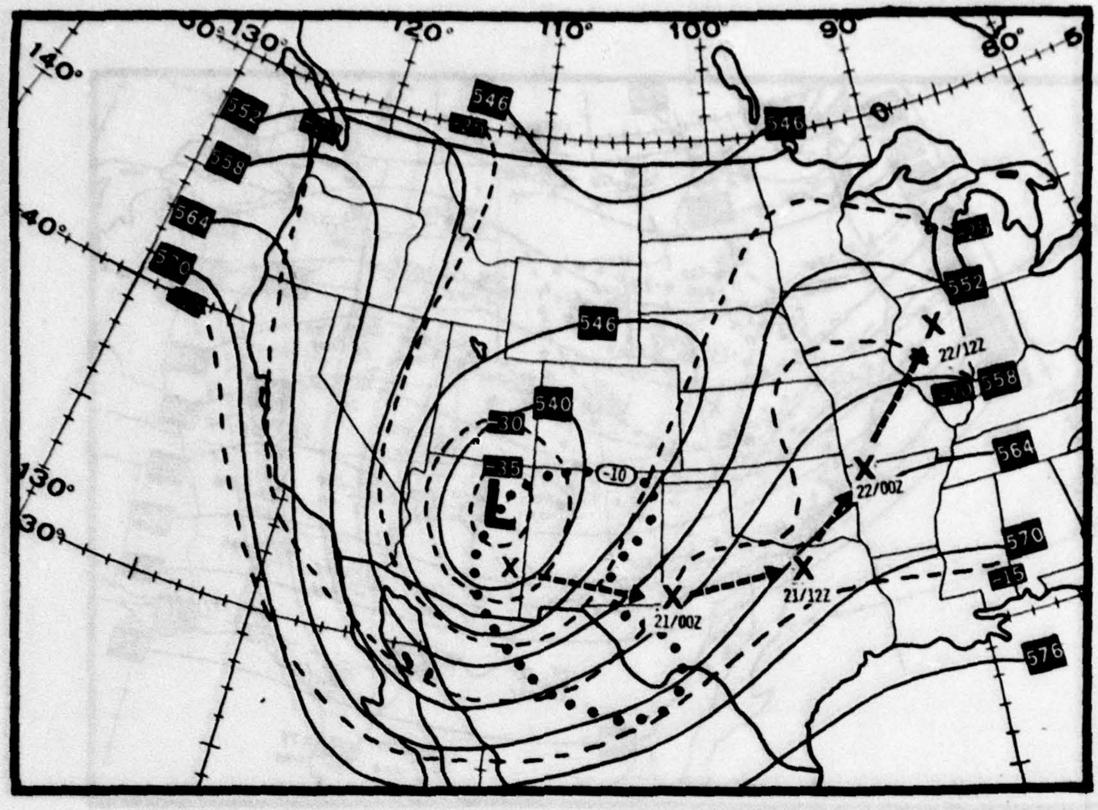


Figure 12c: 12Z 20 Jan 73

EXAMPLE 2 - SHORT WAVE CYCLOGENESIS

In Figure 12c, the low over Idaho has dissipated and a new low has developed over northern Arizona. The cold pocket has intensified to -35°C. The height fall center has filled slightly as it approaches its lowest position in the vicinity of Midland, Texas (MAF). The 300mb maximum isotach area (not shown) has intensified to 130 knots and is moving into the southeast quadrant of the low. The 12-hour height falls continuity is shown and illustrates where the system bottomed out. The 500mb low bottomed out approximately 12 hours later than the height fall center. This system continued easterly and snow, freezing precipitation, rain and thunderstorms developed over the Midwest within 12 hours. By 0000Z, January 22, the 500mb low was located over northeastern Oklahoma with a 989mb surface low over southern Missouri. Moderate to heavy snowfall accompanied this storm over the central and upper Plains states.

From these two examples, it can be seen that the warning time for a potential Midwest snowstorm increases when cyclogenesis develops early within a short wave trough. Of course, any area west of the Rockies can produce cyclogenesis; however, the development area that should be of utmost concern is right at our doorstep - the Rocky Mountain area.

Cyclogenesis over the Rocky Mountains. Cyclogenesis within a deepening short wave trough over areas of the Rocky Mountains may breed a rapid, intense storm system over the western plains in a matter of a few hours. Storm development will often occur between receipt of the 0000Z and 1200Z 500mb Fax analyses. It is imperative, then, to watch for 500mb cyclogenesis which will be evident by deteriorating surface weather in the area of the approaching trough. The patterns that will be shown are similar to the patterns just presented; the only difference is the location of development.

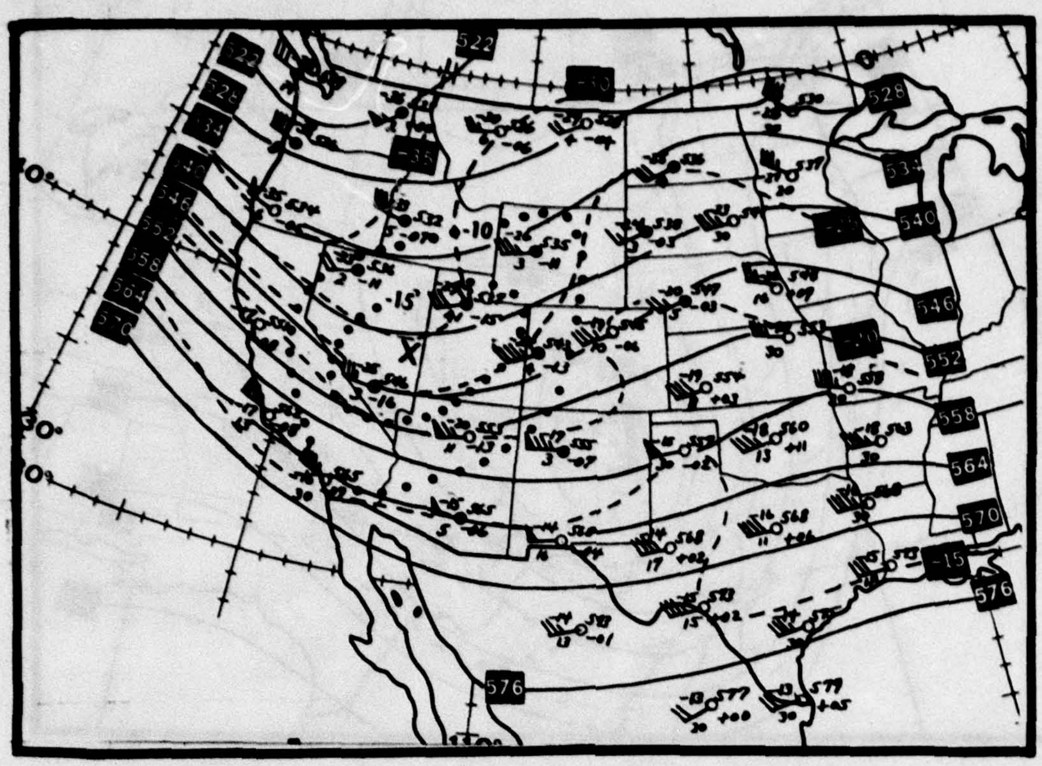


Figure 13a: 00Z 9 Jan 1975

EXAMPLE 1 - SHORT WAVE CYCLOGENESIS, ROCKY MOUNTAINS

Example 1 - Figure 13a shows continued deepening that is occurring in a previously zonal flow pattern. Early signs of zonal flow deepening are cold air advection and a moderate to strong height fall center. (This case study was presented earlier in Figure 8.) In Figure 13a, these two parameters are occurring. The contour gradient is loosening but still is not favorable for identification of low formation. A band of 75 knot winds over lower California indicates that the jet is moving into the trough's bottom.

Figure 13b, 12 hours later, reveals that the trough has deepened as it continues eastward. A weak contour and thermal gradient has become established over the Idaho-Utah area. The height fall center continues southeastward at approximately 24 knots and is over eastern Arizona. All three parameters are occurring together; consequently, cyclogenesis should soon develop within the hatched area as shown in Figure 13b. A strong wind belt (90 knots) is moving eastward across central Arizona and New Mexico.

Twelve hours later, in Figure 13c, a closed low appeared over northern New Mexico. The height fall center has filled and is gradually bottoming out over southern New Mexico. The low turned abruptly northeastward towards central Kansas and a strong height fall center of — 24 was located over central Missouri by 00Z, January 11. This particular storm system produced a blizzard over the central and upper plains states, as will be shown in Chapter 6.

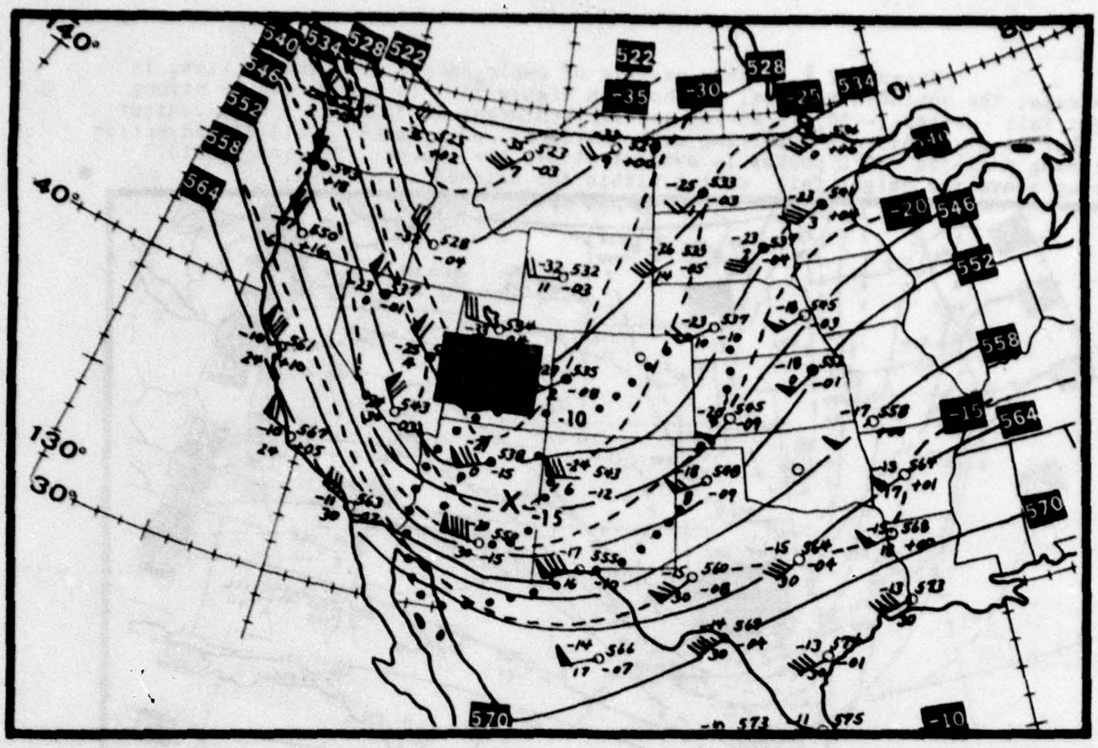


Figure 13b: 12Z 9 Jan 1975

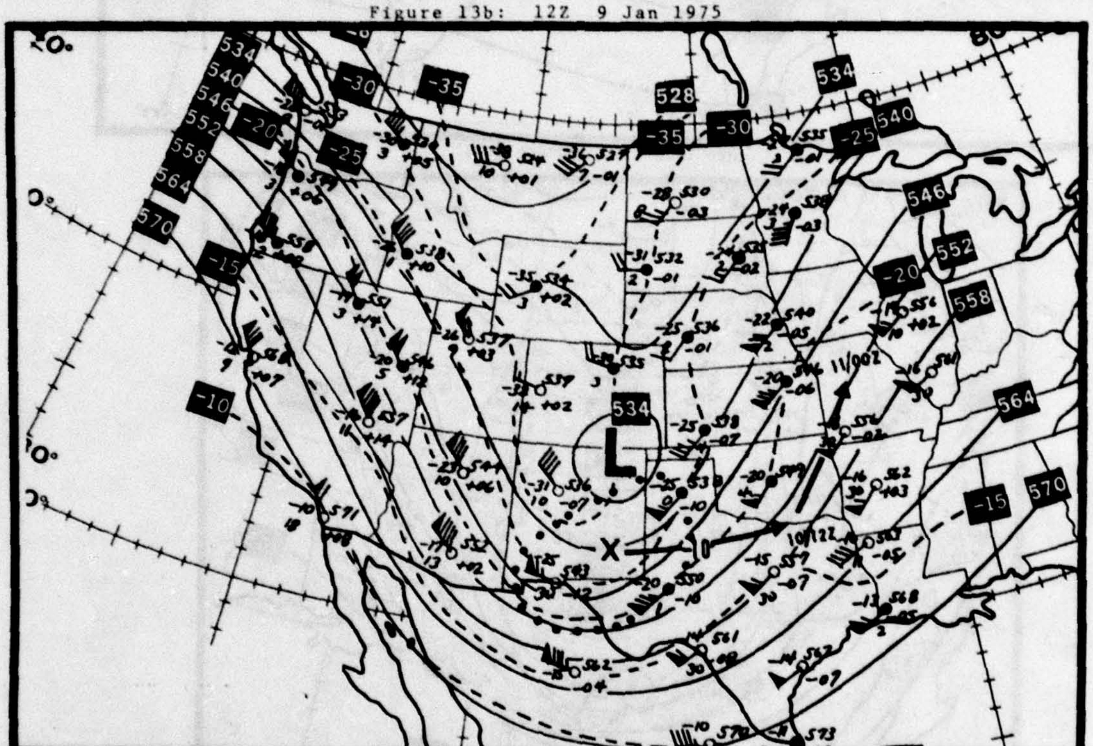


Figure 13c: 00Z 10 Jan 1975

EXAMPLE 1 - SHORT WAVE CYCLOGENESIS, ROCKY MOUNTAINS

Example 2 - Another example of cyclogenesis over the Rockies, in this case, the southern Rockies, is shown in Figure 14. In Figure 14a, a strong height fall center (—20) is moving rapidly southeast at 32 knots. Weak contour and thermal gradients are occurring over nearly all of Arizona. Cold air advection including a closed -35°C pocket is evident within the trough. The low should develop above the height fall center within the hatched area shown.

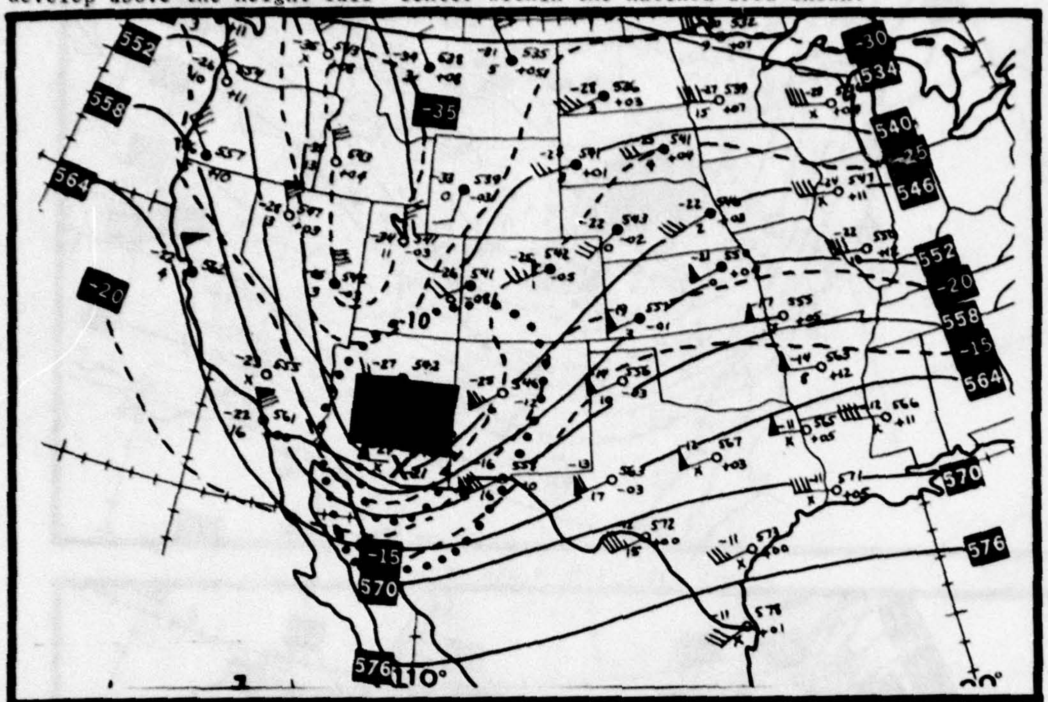


Figure 14a: 12Z 20 Feb 1974

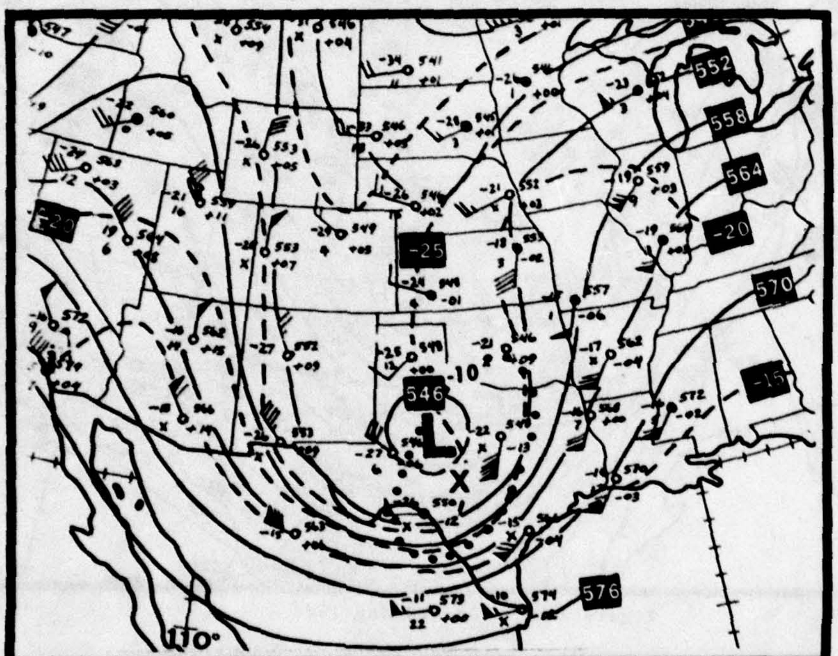


Figure 14b: 12Z 21 Feb 1974
EXAMPLE 2 - SHORT WAVE CYCLOGENESIS, ROCKY MOUNTAINS

In Figure 14b, 24 hours later the closed low has developed and appears over west Texas. The height fall center decreased (−12) as it bottomed out. Shortly thereafter, the center shifted northeastward to northern Arkansas and increased to -15. The entire system turned northeasterly towards eastern Kansas within 12 hours and became a major snowstorm.

LONG WAVE LOW DEVELOPMENT

Cyclogenesis within long wave troughs follow the same subjective rules that have been presented so far. The major forecasting problem lies in steering the sometimes erratic movements of these lows once they develop. As has been mentioned earlier, short wave trough systems, independent of long waves, generally move eastward. On the other hand, following short wave height fall areas within a stationary long wave trough can become frustruating for forecasters. It isn't uncommon to observe a series of weak height fall areas ($\geq$ -10) moving northeasterly up the long wave trough before the main short wave kicks out. Also, height fall areas associated with minor short waves moving southward behind a closed low system within a long wave trough will often alter the low's movement. These tricky height fall movements should not be overlooked, especially when a 500mb low has organized over the western U.S. and the situation looks favorable for storm development over the Midwest.

Frequently, developing upper low systems within long wave troughs initially appear as short waves moving southward from the Gulf of Alaska - western Canada area. The Pacific ridge is usually pronounced, extending northward into Alaska. Short waves moving over the ridge plunge rapidly southward, deepen, and finally settle into the bottom of the long wave as an organized low. Figures 15 and 16 show two such patterns. Long wave troughs present over the central and/or western U.S. frequently retrograde as a new short wave system moves down the westward side of the trough.

Sometimes the Pacific ridge will extend further inland over Western Canada (long wave over the central U.S.) and short wave impulses will shift eastward moving across the northern Rockies and bottom out across the central and/or upper Midwest. Under a normal surface pattern, a surface low would be expected to develop over the northern Rockies and to produce snowfall across the upper Midwest as it moves towards the Great Lakes. Conversely, if the majority of the Midwest is under the dominance of a cold polar airmass and the same upper air pattern described above exists, considerable snowfall can occur over large areas of the central and upper Midwest as the short wave moves across the top of the cold dome. This pattern will be discussed further in Chapter 4. Low level residual and subsequent widespread overrunning over the central U.S. often accompanies these upper air patterns. See 3WWg Tech Note 76-1.

CYCLOGENESIS OVER THE WESTERN U. S.

Example 1 - Figure 15A shows two short wave troughs within a long wave trough. A weak short wave and associated height fall area lies across Nevada and southern California. A second short wave extends southwestward across the Pacific Ocean from the weak contour/thermal gradient off the coastal areas of Washington and Oregon. Weak contour and thermal gradients are noted with each short wave and cyclogenesis could develop in the vicinity of the areas in Figure 15A. The most favorable area for cyclogenesisis within the deepening Pacific short wave (hatched area); the short wave over Nevada lacks good cold air advection and, consequently, should weaken as it moves up the long wave trough. A height falls area associated with the approaching Pacific trough lies somewhere within this area of sparse data. A strong northerly cold flow behind the trough extends northward into Alaska. This cold air advection is our best indication that the Pacific short wave bears watching.

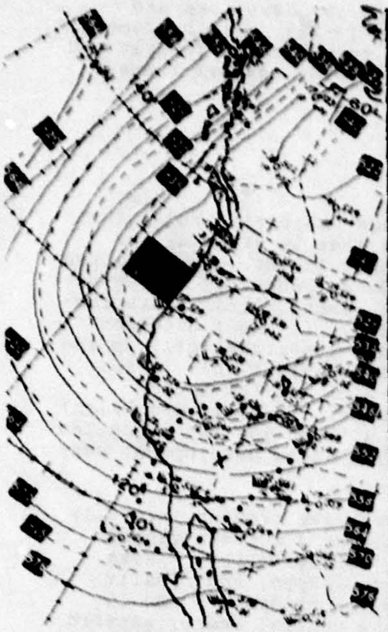


Figure 15a: 12Z 2 Mar 1976

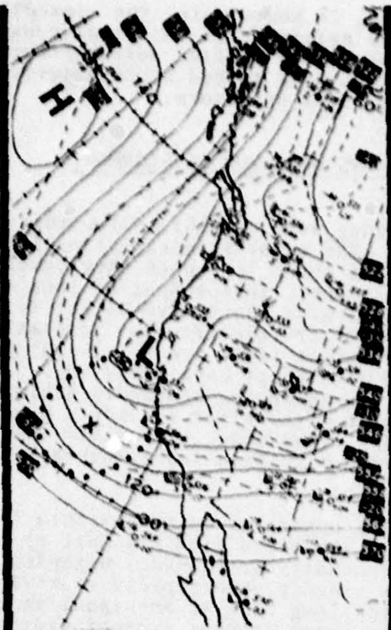


Figure 15b: 00Z 3 Mar 1976

In Figure 15b, 12 hours later, a low appears within the weak contour gradient off the northern California coast. A closed -35°C cold pocket appears within the trough. A height falls area appears to be located south of the developing low and is beginning to enter the central California coast. The Pacific ridge has become more pronounced and a closed high has developed. The weak short wave located earlier over Nevada has now moved northeastward to Utah and has weakened.

The main low has closed off and continues southeastward towards central California, as shown in Figure 15c. The suspected height falls area off the California coast has moved inland and increased in magnitude. This particular low system bottomed out over the southern Nevada-northern Arizona area and turned northeasterly towards the central Rockies, western Nebraska and the Dakotas. This particular closed low feature is not uncommon during the winter season.

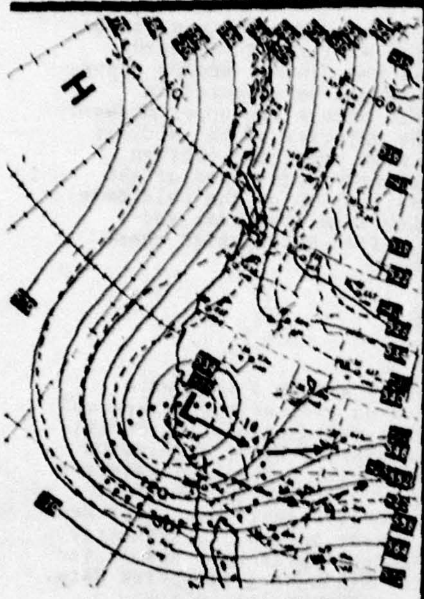


Figure 15c: 12Z 3 Mar 1976

Unlike the low movement in Figure sequence 15, the low will normally continue to move southeastward and eventually settle within the long wave trough over areas of lower California-northern Baja, California and Mexico. These (popularly called the Baja low because of its general location) can remain quasi-stationary for days before finally moving. Minor short waves sometimes will kick out of these systems and move across the Midwest producing short periods of snowfall. Often a strong short-wave impulse approaching from the northwest, which has eroded the Pacific ridge, or a deepening short wave moving east across southern Canada and the northern Midwest will be mechanism that sets the "Baja" low in motion and causes it to move northeastward across the southern and central Rockies. The low fills, and frequently loses its closed contour and thermal circulation features as it moves northeast up the long wave trough. The breakdown of the closed circulation doesn't mean that the system is dissipating. Usually the related surface low system is in the process of attaining maximum development. Example 2 that follows is an excellent case of stationary closed low within a long wave trough that suddenly moved out and produced heavy snowfalls over a large area of the southern Rockies and the Midwest.

FIGURE 15: EXAMPLE 1 - SHORT WAVE CYCLOGENESIS WITHIN LONG WAVE

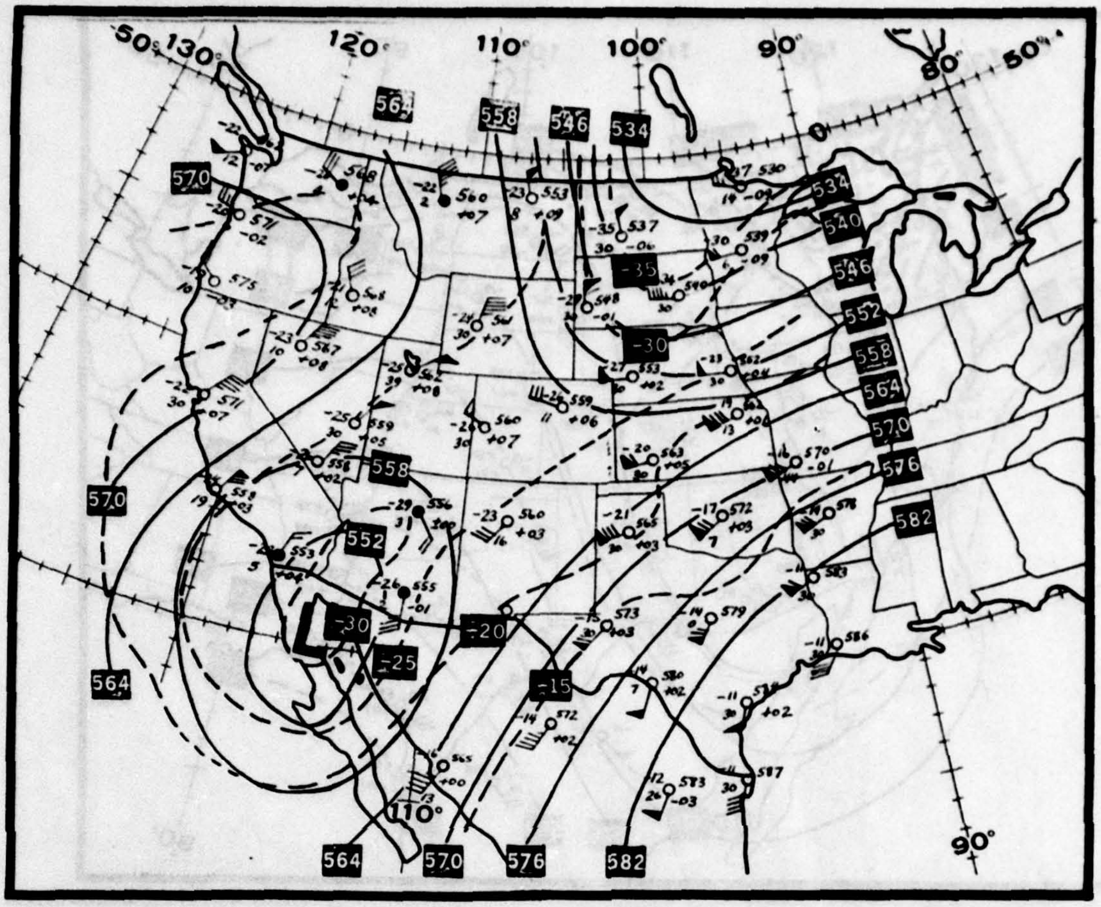


Figure 16a: 00Z 1 Jan 1975

EXAMPLE 2 - SHORT WAVE CYCLOGENESIS WITHIN LONG WAVE

Example 2 - In Figure 16a, a stationary closed low is located over northern Baja, California. No significant height fall area has developed, thus indicating there should be little movement of the system. This low system developed very similarly to the preceding example but continued southward and settled over the areas shown in Figure 16a. Height fall movements south and/or southwest of these lows are excellent indicators that the lows will continue moving southeastward toward the bottom of the long wave troughs. The overall jet stream pattern associated with these systems shown in Figures 15 and 16 are aligned north-south along and/or off the West Coast, curving easterly into the trough's bottom over lower California and northern Baja, and then turning northeasterly across the Midwest.

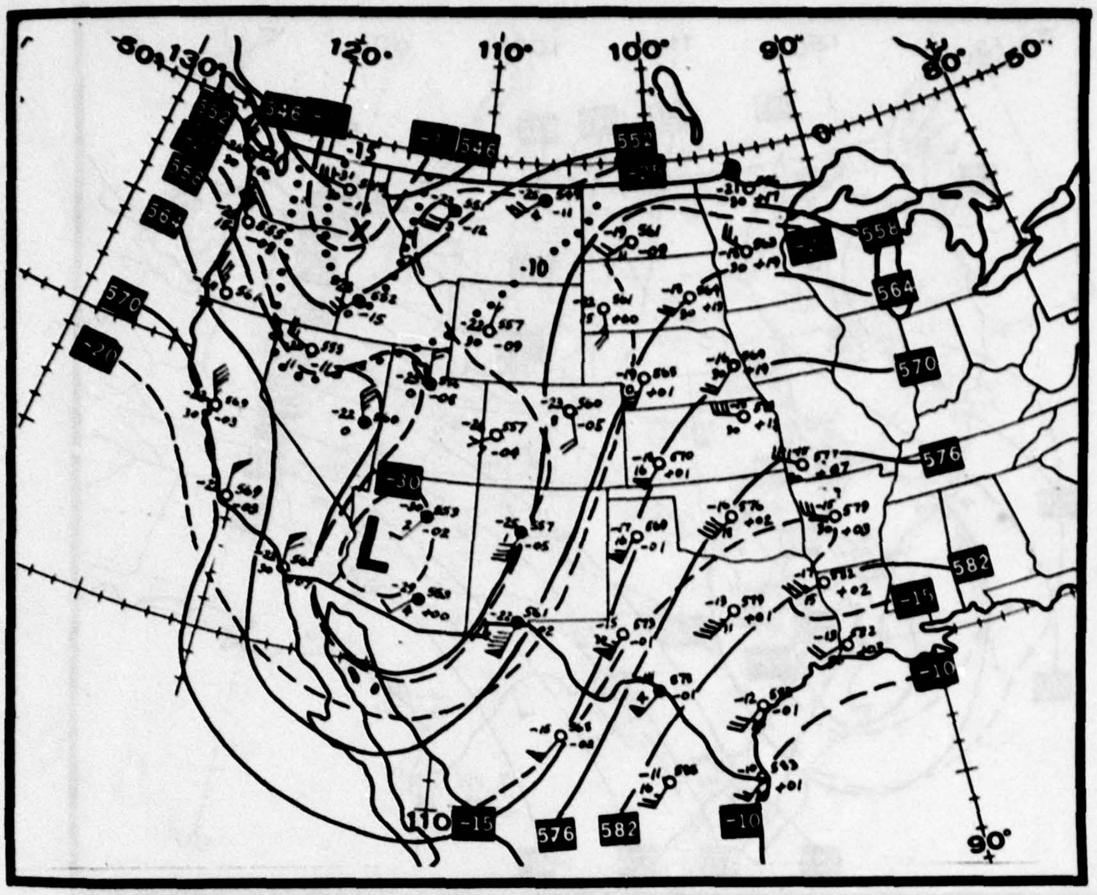


Figure 16b: 00Z 2 Jan 1975

EXAMPLE 2 - SHORT WAVE CYCLOGENESIS WITHIN LONG WAVE

Twenty-four hours later (Figure 16b), the "Baja" low moved northeast into Arizona. No significant height falls are accompanying the low;however, moderate height falls over Idaho ahead of a new short wave impulse probably influenced the "Baja" low to start moving north. At the surface, snow is developing over areas of eastern Arizona and western New Mexico.

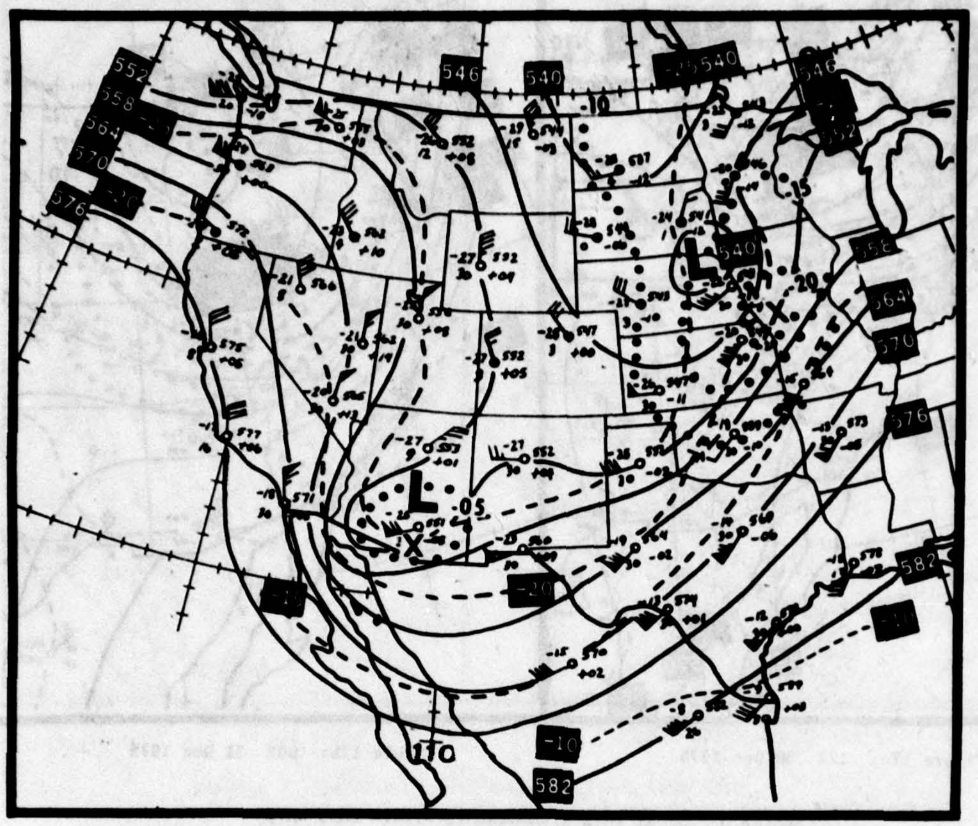


Figure 16c: 00Z 3 Jan 1975

SHORT WAVE CYCLOGENESIS WITHIN LONG WAVE

In Figure 16c, 24 hours later, the low has noticeably intensified and moved rapidly northeastward at 40 knots to Nebraska. A large area of moderate-to-heavy snow has spread rapidly across the central and northern sections of the Midwest. The short wave, previously located over Idaho has split, with the northern portion moving easterly and merging with the Nebraska low. The lower half of the short wave impulse, caught in the long wave's strong northerly flow, moved southward and reached its lowest position over Arizona. Note that cyclogenesis has appeared within the trough over Arizona.

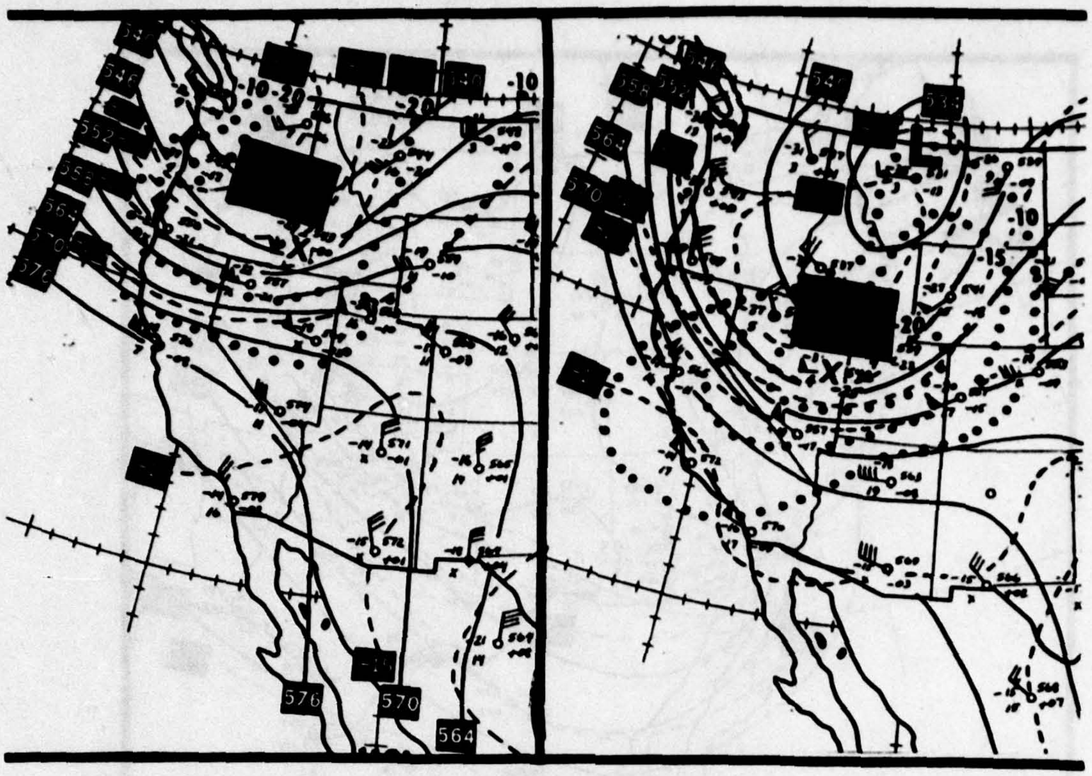


Figure 17a: 12Z 30 Dec 1975 **Figure 17b: 00Z 31 Dec 1975**

EXAMPLE 3 - SHORT WAVE CYCLOGENESIS WITHIN LONG WAVE

Example 3 - This example is presented to show that a short wave impulse, moving southward on the backside of the developing low, can shift the height fall center southwestward. This, in turn, causes the low to move with a southerly rather than an easterly component. The low eventually turnnd northeastward towards the upper Midwest and produced heavy snowfalls over the northern Rockies and the upper Plains.

In Figure 17a, the mean long wave trough lies NE-SW across the Midwest. An intense short wave impulse with a -30 height fall center over Boise, Idaho (BOI), is moving rapidly southeastward. A strong jet stream, evidented by a 100 knot jet at 500mb, is moving easterly across southern Oregon and northern Nevada. Good cold air advection with a -35°C closed pocket is located within the trough. Low formation should occur within the hatched area indicated in Figure 17a.

Twelve hours later (Figure 17b), the low did not appear within the forecast area; instead it developed further to the north over Montana. The strong height fall area, however, continues southeast with the center over Ely, Nevada (ELY). The height fall area extends over a large region, indicating continued strong cyclogenesis. All the parameters ideal for low placement (cold air advection, weak contour and thermal gradient, and a height fall center) point to the low's position over the northern sections of either Nevada or Utah (hatched area) and not Montana.

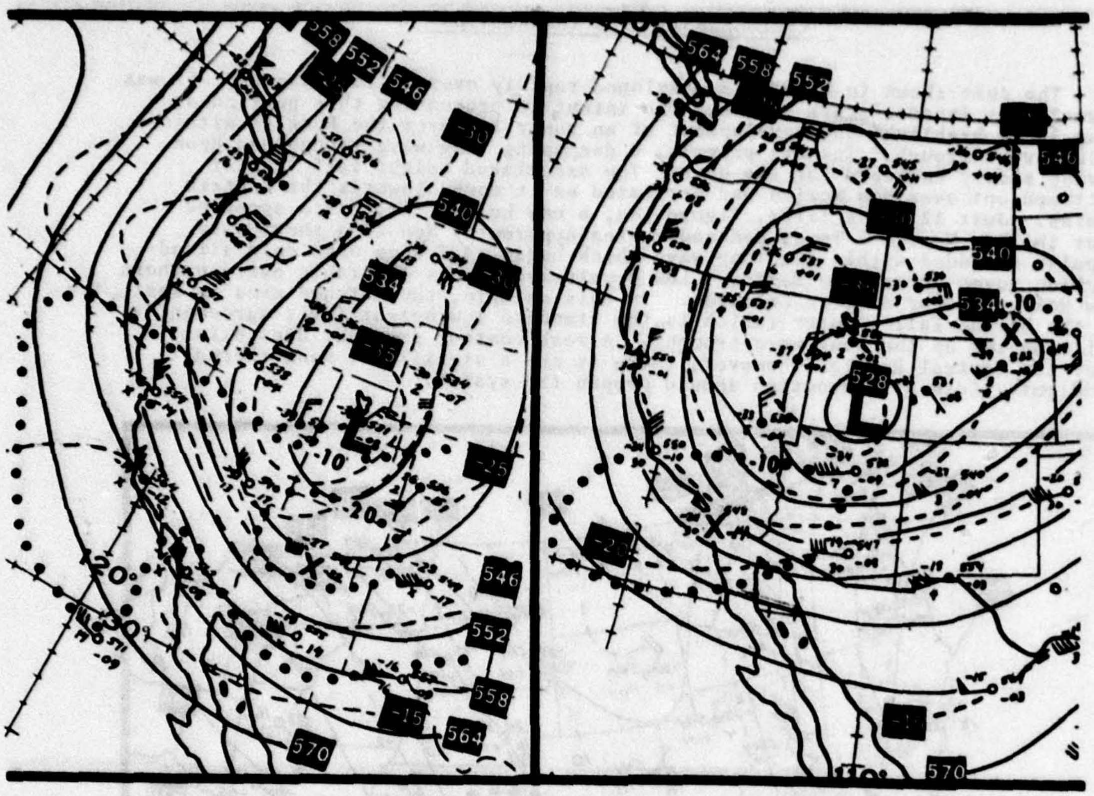


Figure 17c: 12Z 31 Dec 1975 **Figure 17d:** 00Z 1 Jan 1976

EXAMPLE 3 - SHORT WAVE CYCLOGENESIS WITHIN LONG WAVE

In Figure 17c, 12 hours later, the Montana low has dropped south to the Salt Lake City, Utah (SLC), area and appears within the hatched area shown in Figure 17b. The height fall area continues southeastward with the center located over Winslow, Arizona (INW). Note the large elongated height falls area across the southwest U.S. which also extends over the Pacific Ocean. There is another short wave impulse orientated E-W across northern California and paralleling 40°N over the Pacific. A strong E-W cold air trough is also evident north of 40°N. The elongated height fall area coupled with cold air advection and a jet maximum isotach area indicates that a new surge of cold air, represented by the short wave, is moving towards the base of the long wave. This is an important factor in the subsequent movement of the height fall center and low movement during the next 12 hours.

In Figure 17d, 12 hours later, the low has continued to drop southward over southern Utah. The various available facsimile products failed to properly forecast this movement. The height fall center has shifted southwestward towards lower California (-14) and a weaker center is over the Nebraska panhandle. The impulse moving down the West Coast has apparently reached its lowest position. At this point, Midwestern forecasters might have expected the low to move easterly and produce a major snowstorm over the Rockies. The height falls shifted southwestward and, consdquently, further southward movement of the low eliminated that possibility for the present time. The low did, however, bottom out over southern Utah, shifted northeastward and was centered over western Nebraska within 24 hours. Note that the low eventually moved towards the small -10 height falls center over western Nebraska. The height fall center over lower California decreased over the next 12 hours. Heavy snowfall occurred over the northern Rockies, western Nebraska, and a majority of North and South Dakota.

CYCLOGENESIS OVER THE ROCKIES

The case shown in Figure 18 developed rapidly over western Kansas. It was a small but intense storm system. The intent in presenting this particular case is to highlight the development of an upper low over the Rockies within a long wave trough. In this example, a deepening long wave trough had been moving slowly eastward for two days. The associated height fall center bottomed out over New Mexico and decreased as it moved towards the western plains. Just 12 hours later, Figure 18a, a new height fall area appeared over the New Mexico - Texas panhandle area apparently due to a short wave impulse embedded within the long wave which began to deepen when cold air advection moved across New Mexico. Low development looks favorable over northern New Mexico and/or eastern Colorado. In this example, the hatched area is west of the height fall center (which is the standard low/height falls agreement while moving up the long wave trough). A weak contour gradient does exist over the central Rockies; however, there is not a significant weak thermal gradient. Cold air advection should deepen the system.

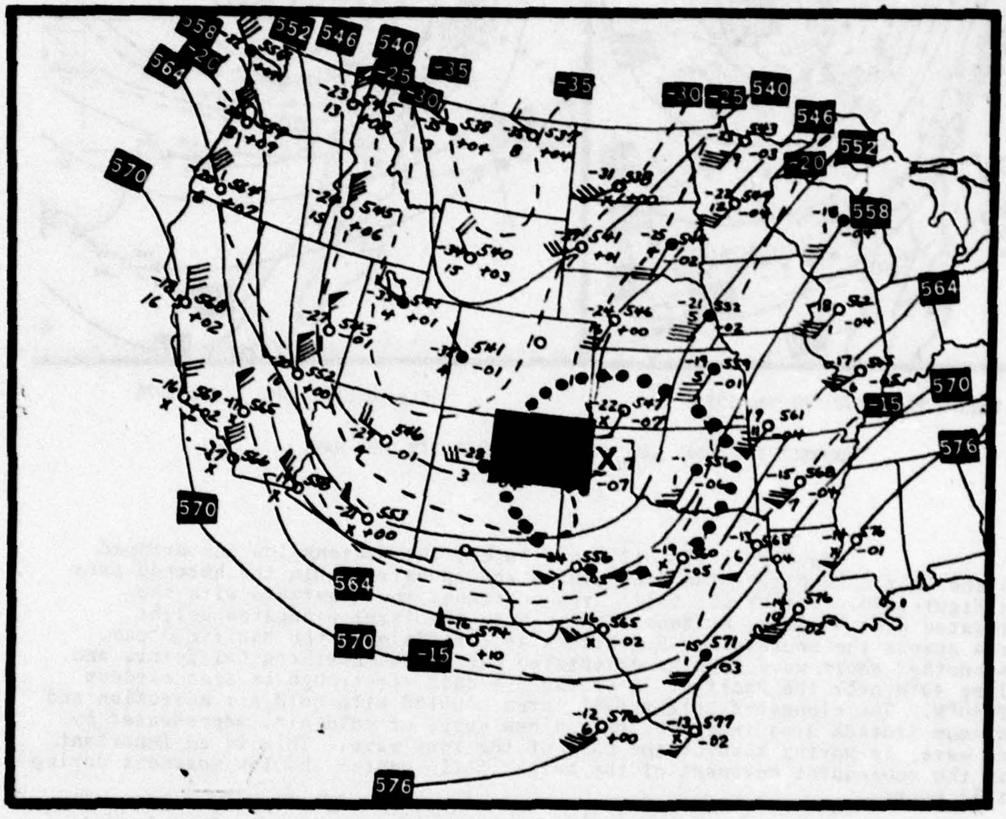


Figure 18a: 12Z 29 Mar 1976

SHORT WAVE CYCLOGENESIS WITHIN LONG WAVE - ROCKY MOUNTAINS

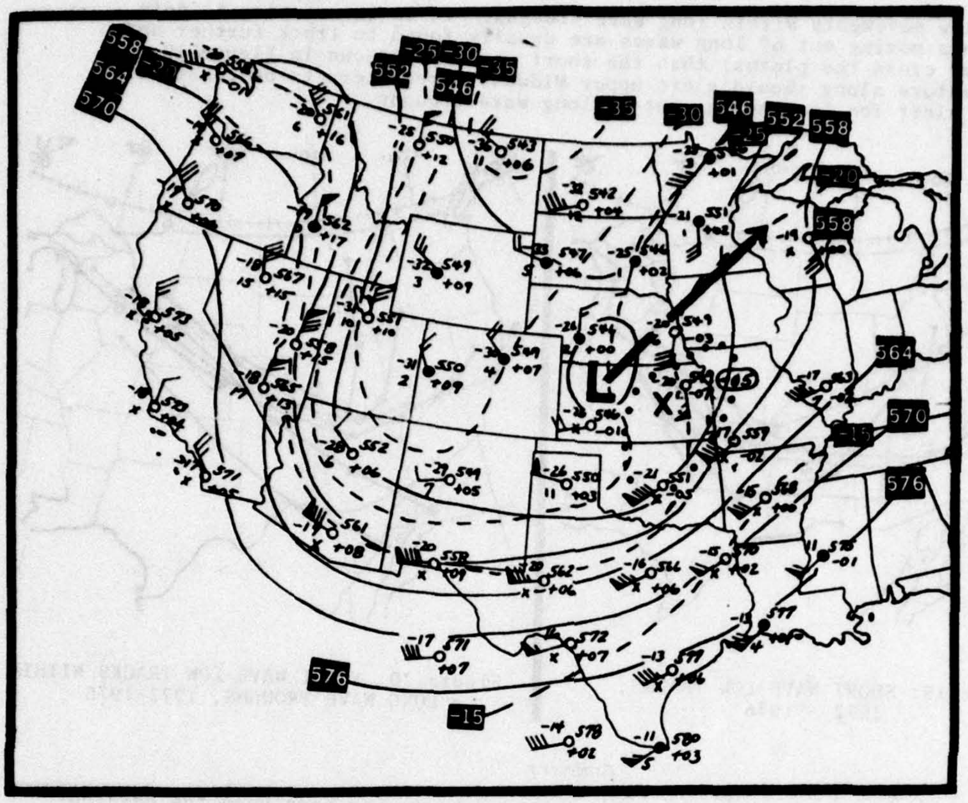


Figure 18b: 00Z 30 Mar 1976

SHORT WAVE CYCLOGENESIS WITHIN LONG WAVE - ROCKY MOUNTAINS

In Figure 18b, 12 hours later, a closed low appears over Kansas. The short wave low is moving northeast towards Omaha, Nebraska, while the main long wave trough axis lies west of the Rockies. The low moved in a straight line from Kansas across northwestern Iowa to central Wisconsin in 24 hours.

This is another example when short wave lows move in a nearly straight line when moving up a long wave trough.

500MB TRACKS OF MAJOR SNOWSTORMS

The paths of selected 500mb lows which produced significant snowfall over areas of the Midwest during the past 4 years are shown in Figures 19 and 20. It can be seen that low formation occurs primarily within troughs west of the Rockies. Figure 19 shows the path of 500mb short wave lows; Figure 20 depicts

500mb low movements within long wave troughs. It is interesting to note that lows moving out of long waves are usually found to track further north (as they cross the plains) than the short wave lows shown in Figure 19. This feature along should alert upper Midwest forecasters to be constantly on the alert for lows moving out of long wave troughs.

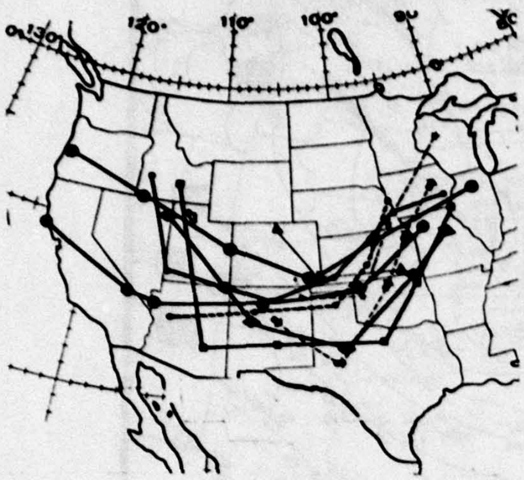


Figure 19: SHORT WAVE LOW TRACKS, 1972 - 1976

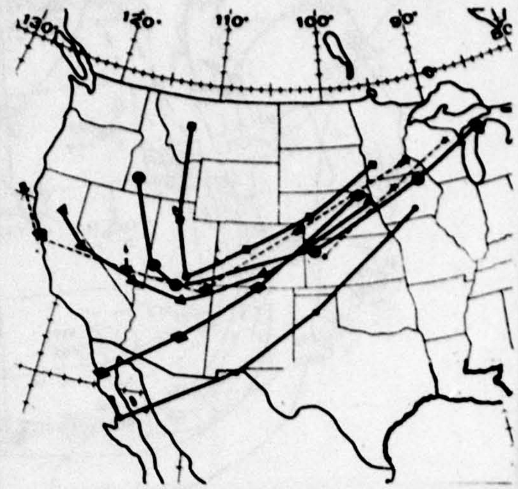


Figure 20: SHORT WAVE LOW TRACKS WITHIN LONG WAVE TROUGHS, 1972-1976

Summary

Throughout this chapter, the primary emphasis has been upon the development of a low pressure circulation and the related long and short wave trough actions at the 500mb level. In the process, identification of parameters conducive to cyclogenesis was made. Three main properties were found to be related to the process of 500mb low development: cold air advection, decreasing contour gradient (troughing action), and height falls. From examination of these combined properties, it was possible to determine the area most favorable for this cyclogenesis process. Thereafter, correlation of height fall tendency to that of the newly formed 500mb low and, likewise, their related movement was presented. Finally, several examples of 500mb patterns and situations that occurred over the western U.S. and that resulted in or contributed to major storm development were shown and discussed.

Forecasters are again reminded that there are situations when cyclogenesis occurs much closer to the Midwest. The development of these storms can be quite difficult to identify, and the subsequent course and consequences of such storms are hard to forecast. It is not at all rare for a storm to develop over the Colorado/New Mexico area and then have it move into the Great Plains during the time period between receipt of the 0000Z and 1200Z 500mb facsimile analyses. Thus, it is imperative to watch for evidence of cyclogenesis (i.e. deteriorating surface conditions) in the area of an approaching disturbance. With this in mind, let's look at, first, the 850mb level and, then, the surface.

CHAPTER 3

850 MB

INTRODUCTION

This chapter will take a brief look at the 850mb level. As the lee-side trough off the Rocky Mountains is significant to the development of storms that occur in the Plains and Midwestern states, examples of related circumstances at 850mb are presented. In the process, low development and movement at this level are shown. Thereafter, the relationship of the 850mb low to the main surface low is discussed. The low-level jet and related moisture found at or near 850mb has been omitted, as such information has been published as a separate volume (3WW Tech Note 76-1, 1 Aug 76, Low Level Moisture Advection.)

LEE-SIDE LOW

Lee-side trough development over the areas of eastern Wyoming, Colorado and New Mexico, western Nebraska, Kansas and Oklahoma and the Texas panhandle commonly occurs when migratory highs recede (move east) from the Midwest. The warmer, southerly flow induces the formation of small weak surface lows east of the Rockies. During the winter months, stationary surface fronts and lows separating cP air from mP air are frequently present along the lee-side trough. Lee-side lows seldom appear at the 850mb level; normally a weak contour gradient will exist. However, particular attention should be given when a 850mb low does appear within the 850mb lee-side trough. Frequently, this 850mb low development is a warning of an approaching upper low or that cyclogenesis is occurring within an upper trough. Lee-side 850mb low development is not likely to be significant when the Midwest, including areas east of the Rockies, is under the dominance of a polar airmass.

TYPICAL DEVELOPMENT OF LEE-SIDE 850MB LOW

Figures 21 and 22, a and b, show typical development of an 850mb low within the lee-side trough in relation to an approaching 500mb trough/low. In Figure 21a, note the wide contour gradient trough over Wyoming and Colorado. The 500mb low is indicated as being over northeastern Nevada; however, no associated 850mb low is present. At this same time at the surface (now shown) there were two low centers on the mP cold front in western South Dakota and southern Utah with a third low (the lee-side low commonly referred to as the Colorado low located in eastern Colorado). By twelve hours later, as shown in Figure 21b a closed low has developed at 850mb over eastern Colorado within the warm tongue or thermal ridge. The 500mb low has moved southeastward. During the next twelve hours (not shown), the Colorado low moved to the Lubbock (LBB), Texas, area and became associated with the upper low which had moved into central New Mexico. The two surface lows on the mP frontal boundary either dissipated or merged with the lee-side low.

Another example of lee-side trough development is shown in Figure 22a. This figure is used to bring out another point. Note the two lows along the northern U.S. border. Neither of these lows is the main surface feature to watch (for storm development) when 500mb cyclogenesis is occurring over the central and southern portions of the western U.S. Similar lows are often located along the stationary arctic front or are the dissipating lows at the top of an approcahing mP cold/occluded front from the Pacific Northwest. These lows, located north of the intensifying lee-side low, usually dissipate and are replaced by colder air. By twelve hours later, in Figure 22b, a closed 850mb low has appeared over eastern Colorado, while the two lows along the border have dissipated. The 500mb low has begun to develop

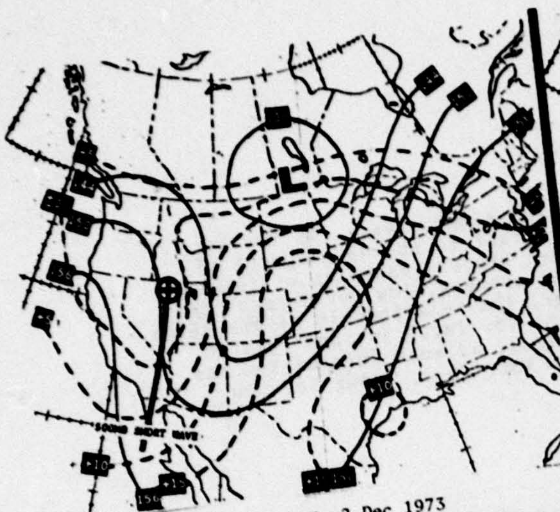


Figure 21a: 12Z 2 Dec 1973

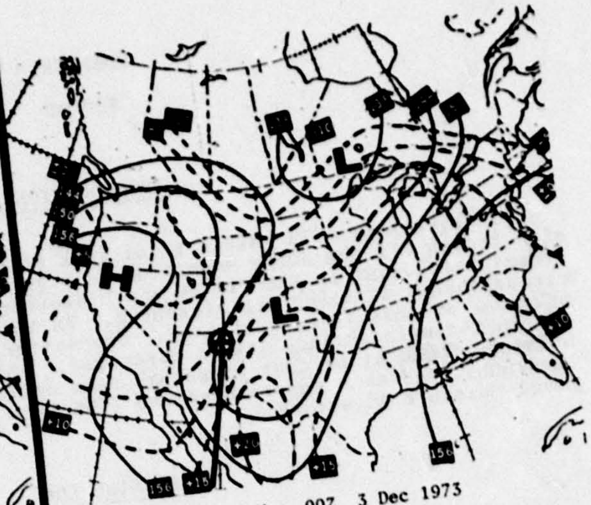


Figure 21b: 00Z 3 Dec 1973

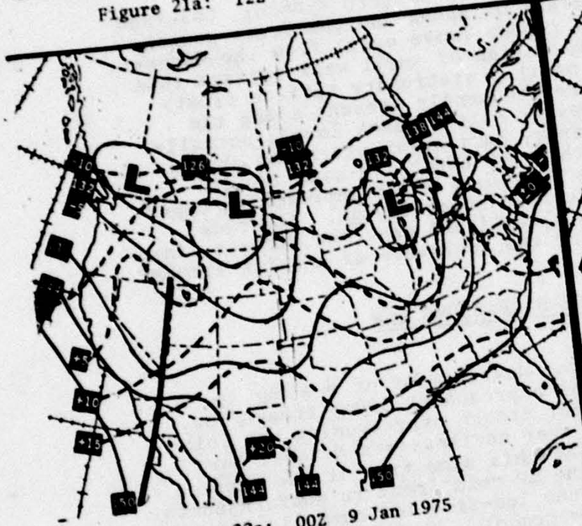


Figure 22a: 00Z 9 Jan 1975

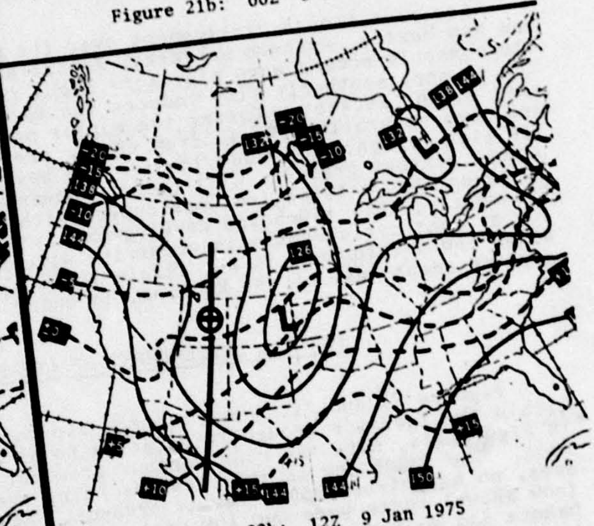


Figure 22b: 12Z 9 Jan 1975

LEE-SIDE LOW 850MB DEVELOPMENT

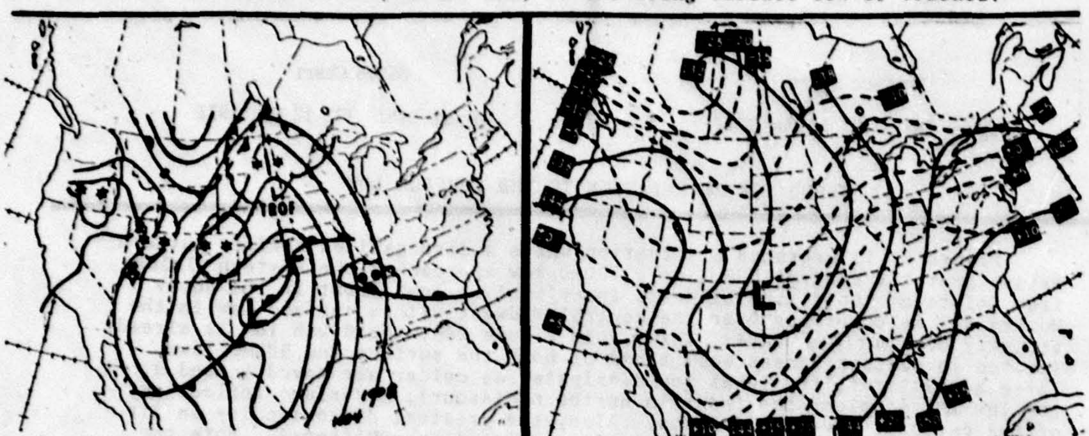
over central Utah. Twelve hours later (not shown), the Colorado low moved south to northeastern New Mexico at the surface level and stacked with the 500mb closed low, which also moved to northeastern New Mexico. In both occurrences, the 850mb lee-side low moved southeastward from Colorado as it became part of the storm system. This southeasterly movement is the general rule when upper lows are still moving southeasterly towards the New Mexico - southern Colorado area until the system bottoms out within the 500mb trough.

Developing lows within short waves at 500mb over the western U.S. often do not have an associated 850mb low, since development is occurring first at the higher levels and then downward. Eventually, the 850mb low does appear. In most occurrences, the low will move into or develop within the lee-side trough.

Developed upper lows which move in from the Pacific or the Gulf of Alaska, as a general rule, already have vertical support to the surface; therefore, an associated 850mb low over the western U.S. should be considered as the main low. If the upper system is moving southeasterly towards the southern Plains (bottoming out) the associated 850mb low will likely move into the lee-side trough and intensify.

850MB LOW IN RELATION TO THE SURFACE LOW

As previously mentioned, it is not uncommon to find two or more lows on the surface chart over the western U.S. (in addition to the lee-side low) during the development of an upper low. There is often a low and/or wave along the approaching mP cold/occluded front. As stated earlier, these lows will either dissipate or merge into the lee-side low as the entire system organizes over the western plains. Figures 23 and 24 show mP cold fronts and lows and 850mb low positions during the initial stages of development over the Midwest. The main purpose of these two selected figure sequences is to insure that the right surface low and potential areas of surface cyclogenesis are followed in relation to the 850mb low. Timing of a deepening storm system could be many hours off, if the wrong surface low is tracked.



Surface Chart

Figure 23a: 00Z 10 Jan 1975

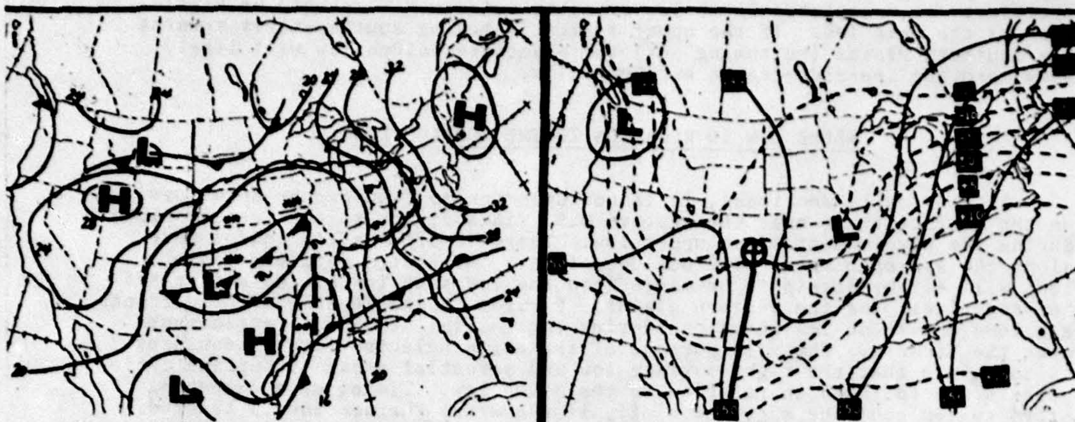
850mb Chart

Figure 23b: 00Z 10 Jan 1975

850MB LOW IN RELATION TO THE SURFACE LOW

There are occasions when the mP cold front will become stationary over the central and western plains when the related upper trough slows down while undergoing cyclogenesis over the western U.S. During this period, two or more frontal lows will appear and move up the front. Identification of the main frontal low can be made by following the 850mb low. Figures 23a and 23b show such a setup. In Figure 23a, two waves/lows appear along an mP front over the central plains. The question arises as to which frontal low is the main low. A quick check at the 850mb level (Figure 23b) shows

that the Texas wave/low should become the main low. Within 12 hours, the surface low over eastern Kansas dissipated and the Texas low had moved northeasterly and (several hours after snow had been forecast for the central plains), became an intense storm over the central and upper plains and much of the western Great Lakes region.



Surface Chart

Figure 24a: 12Z 12 Dec 1972

850mb Chart

Figure 24b: 12Z 12 Dec 1972

850MB LOW IN RELATION TO THE SURFACE LOW

Figure 24 illustrates a situation where a disorganized surface pattern exists over the central U.S., as a 500mb low approaches the western plains from Colorado. Cold frontogenesis (previously a lost front in the Rocky Mountains) is occurring over the central Midwest with a surface low in the vicinity of Amarillo (AMA), Texas. In Figure 24b, the 850mb low is already located in eastern Kansas well ahead of both the surface and 500mb lows. Three hours later, the Texas low dissipated as colder air moved in and a new low formed along the front in northern Missouri, a surface reflection of the easterly moving 850mb low. Also, the greatest discontinuity in air masses due to warm, moist southerly flow existed over Missouri. Note the thermal gradient over Missouri in Figure 24b. Low formation was rapid, and a major storm resulted. It is evident that steering and timing of precipitation problems could have occurred if the surface low in Texas had been considered the major low.

SUMMARY

Forecasters should carefully watch for development of a low at the 850mb level along the east slopes of the Rocky Mountains. Such a development may verify the potential for cyclogenesis in the 500mb trough. As has been discussed in this chapter, determining the existence or inception of such a low at this level is important to proper identification and correct forecasting of the subsequent movement of the main surface feature. Thus, knowing the contributions at the 850mb level to the storm system, as a whole, is vital to forecasting onset and extent of precipitation along the storm's path. In conclusion, the reader is again reminded that helpful information can be found in 3WW Tech Note 76-1, Low Level Moisture Advection.

CHAPTER 4

SURFACE

INTRODUCTION

In this chapter, surface synoptic patterns associated with deepening upper troughs over the central and western U.S. will be discussed. Included will be cold air sources, frontal and pressure systems and other significant features which occur during the development period. Discussion of the associated 500mb trough/low and, by exception, the 500mb height fall center related to the developing surface system will be included. Chapter 5 will focus on significant features associated with the developing storm as it begins to organize over the Rockies and the western plains.

COLD AIR SOURCES

A forecasting decision on whether snow or rain will occur is a routine problem for locations in the central and southern Midwest. The source of the cold air needed to produce freezing and/or frozen precipitation should be considered when a storm system is moving out of the Rockies to the western plains. Naturally, if cold air is present and is expected to persist, the occurrence of snow is likely. Figures 25 to 27 show three surface patterns favorable for advection of cold air into Midwest storm systems. In these figures, the assumption is made that warm air has been advected northward ahead of the storm system and a decision as to whether cold air will feed into the low in time to change rain to snow has to be made. These figures will be helpful in recognizing surface patterns likely to produce cold advection into a storm system. The frontal systems depicted are not necessarily ideal positions; these examples were selected for convenience.

The most frequent source of cold air is as shown in Figure 25. Often a stationary front or a slow moving cP cold front will appear through the upper Midwest separating cold polar air from warmer, modified cP and/or mP air. Sometimes, troughs will appear on the surface chart rather than fronts. Treat these troughs as potential fronts; it isn't unusual at all to see analyzed troughs changing to cold fronts when the cold air north of the trough begins to move southward behind low systems. Snow can occur prior to the arrival of cP air, provided the mP air drawn into the low system from the Rockies is cold enough. The presence of cP air will increase the area of snowfall.

Building ridges extending from the Pacific high over the western U.S. often produce high pressure over the Idaho-eastern Oregon-Washington area. Occasionally, the ridge extends northward into Canada, allowing cold air to move southward along the east side of the ridge. Figure 26 shows such a pattern.

Figure 27 shows the absence of the usual cP high over western Canada. Instead, the cold air source is located over the eastern sections of Canada and/or the U.S. Slow moving, receding highs[1] over these areas will sometimes extend a ridge westward through the Great Lakes and southern Canada to the upper Midwest. Developing storms over the central U.S. induce these cold air ridges to move southwestward into these storm systems.

MARITIME POLAR FRONTAL SYSTEMS

During the course of the winter season, there will be many mP cold/occluded frontal systems which will enter the Pacific Northwest. Most of these frontal systems move across the Rockies and into the Midwest as relatively dry and weatherless fronts. There are, however, synoptic situations in which these frontal systems are a

1. Throughout, the term "receding high" means a high moving away (thus receding) to the east from the Midwest.

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Figure 25: Cold Air from Main High - Western Canada

Figure 26: Cold Air from Main High - Western U.S.

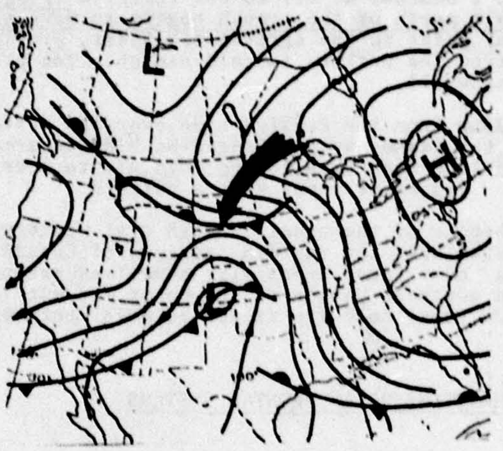

Figure 27: Cold Air from Main High - Eastern U.S./Canada

COLD AIR SOURCES

forewarning of major storms over the Midwest. Maritime polar cold/occluded fronts from the Pacific Northwest that are associated with a developing upper system over the western U.S. normally move in a southeasterly direction towards the Midwest. The first indication of a deepening upper trough/cyclogenesis is a lagging front with wave/low development usually over the Nevada-Utah area. The frontal wave/low will often persist as it moves across the Rockies and will either dissipate or merge with the lee-side low. Then, the lee-side low becomes the major low and intensification is rapid. On the other hand, there are occasions when upper trough/cyclogenesis development will occur much closer to the Midwest and little warning of an impending storm can be determined from the approaching mP frontal system. In these cases, an mP frontal system lacking wave/low development across the Rockies can suddenly develop a significant low along it as it moves over the western plains.

Maritime polar fronts crossing the Rockies are sometimes hard to locate and often will be discontinued on the facsimile surface analysis. Often, the only clue that a surface discontinuity still exists in relation to an upper trough over the western U.S. will be the existence of an inverted trough pattern and/or surface low in that area. It is important to maintain continuity on these weak systems, especially when cyclogenesis is occurring aloft over the central and southern Rockies.

The presence or absence of a migratory high pressure system over the northern Rockies and/or the upper Midwest during the period when upper level deepening is occurring over the western U.S. determines the orientation of mP frontal wave/low formation over the Midwest. Figures 28 and 29 depict these two anticyclonic pressure patterns. No investigation was made to relate these two patterns with upper air features due to the shallowness of migratory high pressure systems. Migratory highs can persist and/or move southward under an upper southwesterly flow.

Figure 28 depicts the normal pressure pattern sequence across the U.S. prior to major storm formation over the Midwest. Migratory cP highs over Canada or mP highs from the western U.S. are moving towards the eastern U.S., resulting in surface trough development and eventual low formation along the lee slopes of the Rockies. Stationary or building cP highs over northern Canada often extend a cold polar ridge into the upper Midwest as shown in Figure 28. Gulf stratus often develops and moves rapidly northward into this type of pressure pattern (See 3WW Technical Note 76-1).

In Figure 29, a persistent zone of high pressure extends from the Pacific Northwest across the Rockies into the upper Midwest. Lee-side trough/low development is not favorable under such an anticyclonic, cold airmass; consequently, the surface cyclonic pressure pattern associated with the approaching mP system would be represented by an inverted trough configuration. Often under these circumstances, the thermal low located over the northern Mexico-southern Texas area has a much lower than normal central pressure. The high pressure zone shown in Figure 29 does not necessarily mean that potential storm development would be dampened or its track would be confined to the southern plains states. This pattern has been closely followed by several major storms that eventually moved across the Midwest. Conversely, what looks like an ideal storm pattern developing over the southern Rockies can be depressed or its track shifted southward, if the high pressure system shown in Figure 29 is moving southward. Residual stratus and widespread overrunning precipitation is often associated with this type of pressure pattern.

The following synoptic patters (Figures 30 through 36) will be identified as one of the two anticyclonic features shown in Figures 28 and 29. Additionally, Figures 30 through 36 will be further identified as either mP frontal systems or mP inverted trough/low pressure systems. No attempt has been made to classify the numerous frontal wave/low variations that appear over the Rockies prior to storm development. The intent has been, instead, to identify the overall large scale pressure patterns which exist in advance of mP systems headed towards the Midwest.

1. Maritime Polar Frontal (Receding High Pressure: Figure 28)

Three examples of this pattern will be shown. The first example will show a typical setup prior to storm development within the lee-side trough. The next two examples are actual occurrences and have been selected to show storm development over the western U.S. (early warning) and storm development over the Great Plains (little warning). These two examples (and all subsequent examples) will be shown in two parts: Figure a depicts the time period prior to storm development over the Midwest and Figure b shows the synoptic pattern 24 hours later. Included with each figure are 500mb trough and/or low positions relating to the main surface low and areas of precipitation.

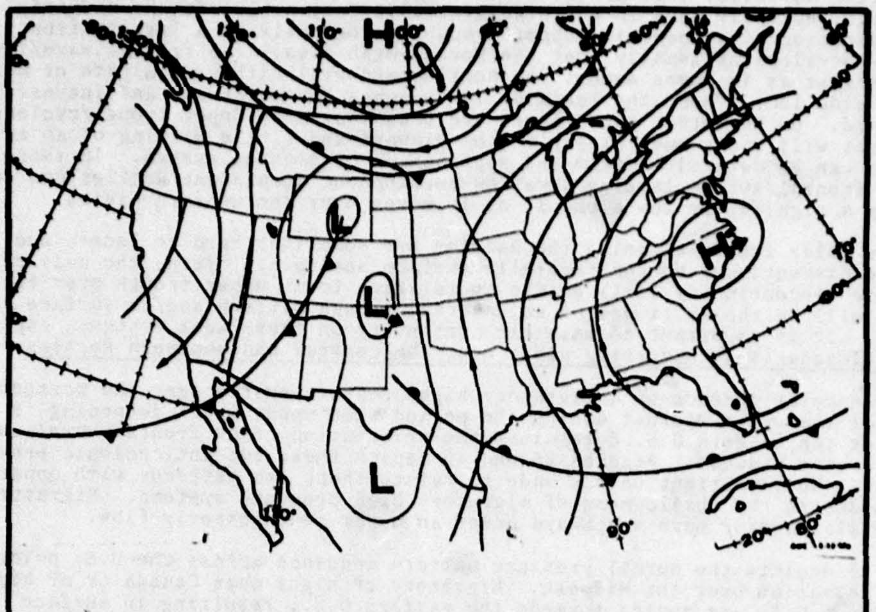

FIGURE 28: HIGH PRESSURE RECEDING FROM THE MIDWEST

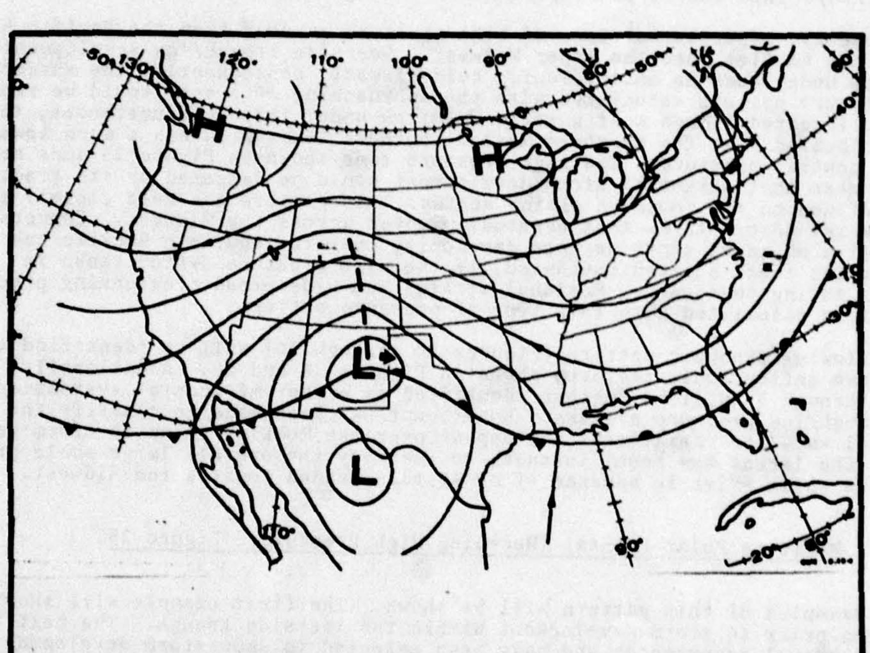

FIGURE 29: PREVAILING HIGH PRESSURE OVER THE MIDWEST

a. Typical Surface Pattern (Example 1, Receding High)

Figure 30 shows a typical surface pattern 12 to 24 hours prior to a major storm over the central Midwest. Each feature is identified by a letter in Figure 30. The mP cold front with an associated low (A) is moving southeasterly across the Rockies and is approaching the lee-side low/trough (B). Often, two or more surface lows, along with the lee-side low, will appear over areas west of the Rockies during upper level intensification and/or cyclogenesis. Identifying the main surface low and where it will eventually organize can be a problem; identification and steering of the main surface low will be discussed in Chapter 5. The high (C) located over the Colorado Plateau area appears routinely on the surface chart. This high does not move out ahead of an approaching mP system. Instead, it will dissipate as warmer southerly low level flow advects into the area.

There is usually a stationary front which extends southeastward from western Canada to eastern Colorado along the Rocky Mountains (D). This frontal system is a semi-permanent feature during the winter months and is established when polar or arctic air is present east of the Rockies. The placement and orientation of this front over the Rockies is dependent upon the strength and thickness of the cold polar air. Usually, one or two waves/lows are found along this boundary; however, their existence is usually of no significance to storm occurrence over the central U.S. unless upper trough/cyclogenesis is occurring west and southwest of the Rockies. Often, this stationary front will develop eastward (E) either as a front or trough over the central or upper Midwest depending upon the strength of the cP ridge over Canada and the northward advection of warmer air. This developing front/trough can become a significant feature in that it frequently develops the characteristics of a warm front, even though it is often depicted as a stationary front or as a surface trough. At other times, this east-west surface troughing can be an indicator that colder air is beginning to push southward and that the trough development is the leading edge of cold air. Often, the first appearance of snow will develop along this boundary and northward within the colder air mass many hours prior to main storm development over the central and/or southern Rockies. The stationary front (F) in the western Gulf of Mexico, under return flow on the back side of the receding high can also begin moving northward and be accompanied by moist, warm gulf air.

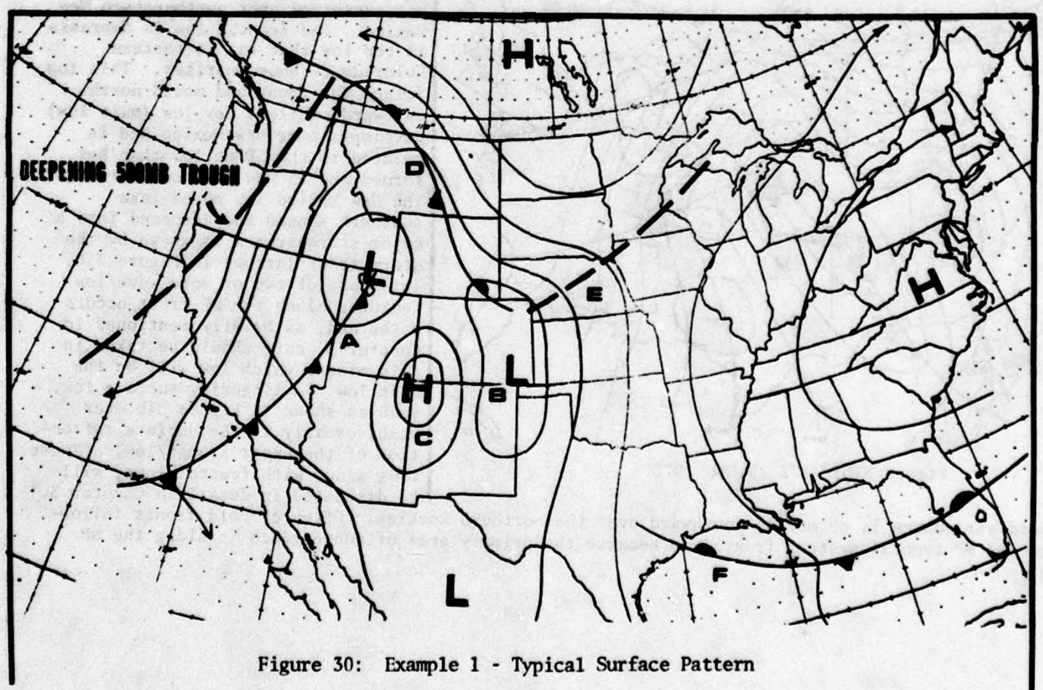

Figure 30: Example 1 - Typical Surface Pattern

b. Cyclogenesis Over the Western U.S. (Example 2, Receding High)

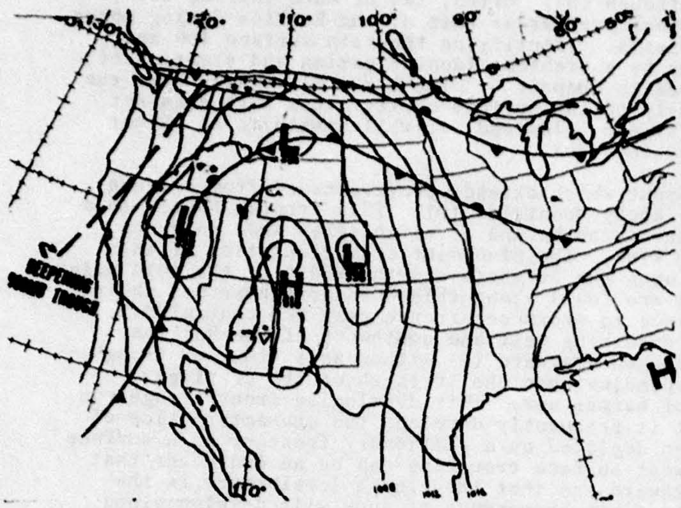

Figure 31a: 12Z 28 Dec 1972

In Figure 31a, the approaching mP frontal system has already started to wave with an associated low over Nevada. The lee-side trough/low has developed and warm air is advecting over the Midwest. The cold air source is a high located over the Hudson Bay area. A discontinuity zone between modified cP air and warmer mP air exists across the upper Midwest. A stationary colder cP frontal zone is located in southern Canada. An intensifying 500mb trough from California to Washington is moving southeasterly.

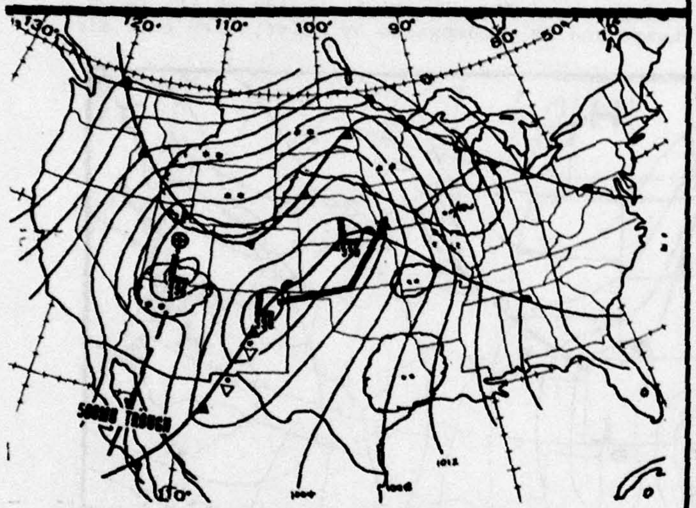

Figure 31b: 12Z 29 Dec 1972

In Figure 31b, the main surface low has organized over northeastern New Mexico. The frontal low in Nebraska is the low that was in eastern Colorado 24 hours earlier. This low joined the front and moved northeastward, while a new low (main low) developed over New Mexico and is related to the 500mb low that has formed and is now located over Utah. The New Mexico low moved into southern Kansas and deepened into a major storm system as shown by the storm track (arrow) in Figure 31b. This case of two or more wave/low features along the mP front occurs often and, as briefly mentioned in Chapter 3, care should be taken in determining which low will be the main low. A lingering surface low, such as shown in Figure 31b over Utah, usually is the surface reflection of the upper trough/low. (These lows, along with frontal lows, will be discussed in detail in Chapter 5.) The cold air source is cP moving southward over the northern Rockies. Often cP cold fronts following behind mP frontal systems frontolyze because the primary area of convergence is along the mP front.

FIGURE 31: EXAMPLE 2 - CYCLOGENESIS OVER WESTERN U.S.

c. Cyclogenesis Over the Rockies/Midwest (Example 3, Receding High)

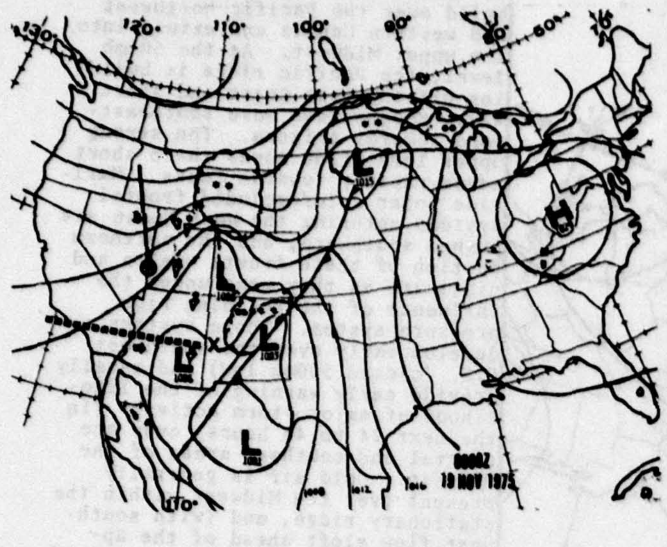

Figure 32a: 00Z 19 Nov 1975

Figures 32a and 32b show major storm development along an mP cold front over the southern Rockies and western plains. This case is an example where the mP front has moved out into the central plains and is becoming stationary due to either cyclogenesis within the upper trough over the Rockies or a new short wave bottoming out and, thus, deepening the long wave trough over the western U.S. The mP front will slow down in response to deepening of the upper system and eventually the upper system will catch up and stack with the main surface low along the front. Note the four surface lows in Figure 32a; the main surface low is located over eastern New Mexico. The frontal low over western Minnesota traveled up the front from southwestern Nebraska and produced only a short period of light snow in the vicinity of the surface low.

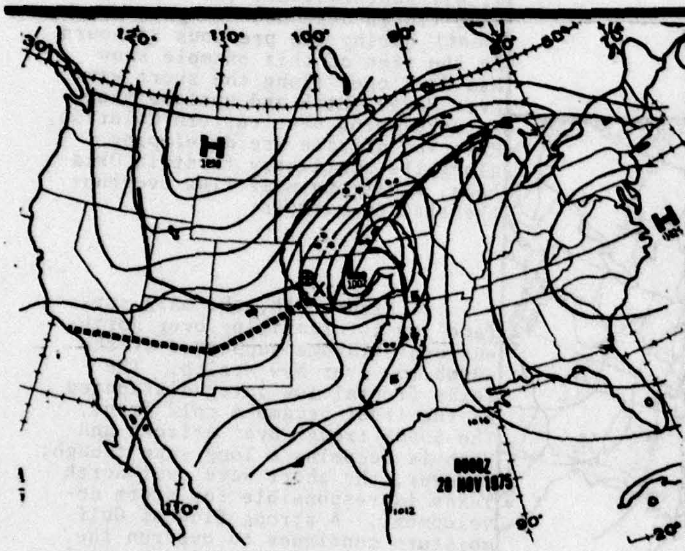

Figure 32b: 00Z 20 Nov 1975

In Figure 32b, the surface low which was over New Mexico, has organized and intensified in the past 12 hours. The 500mb low has now caught up with and nearly stacks with the surface low over central Kansas. Blizzard conditions are occurring over northwestern Kansas and central Nebraska. The 500mb height fall center track would be very helpful in determining where the main surface low would organize. This particular example is explained in more detail in Chapter 5.

FIGURE 32: EXAMPLE 3 - CYCLOGENESIS OVER THE ROCKIES/MIDWEST

2. Maritime Polar Frontal (High Pressure Over Midwest: Figure 29)

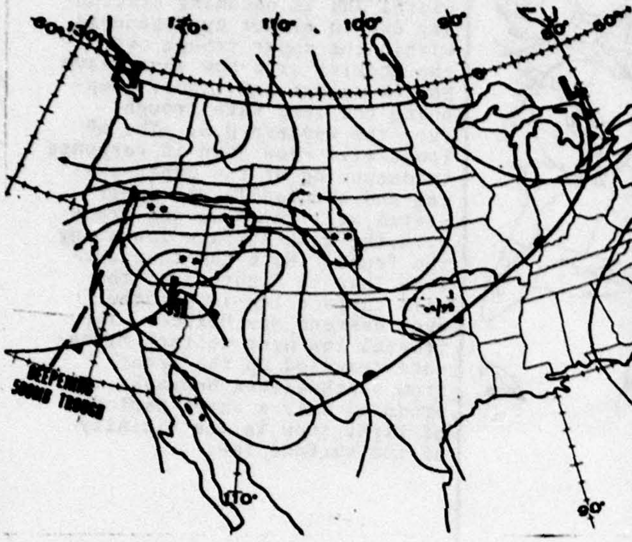

Figure 33a: 12Z 2 Jan 1971

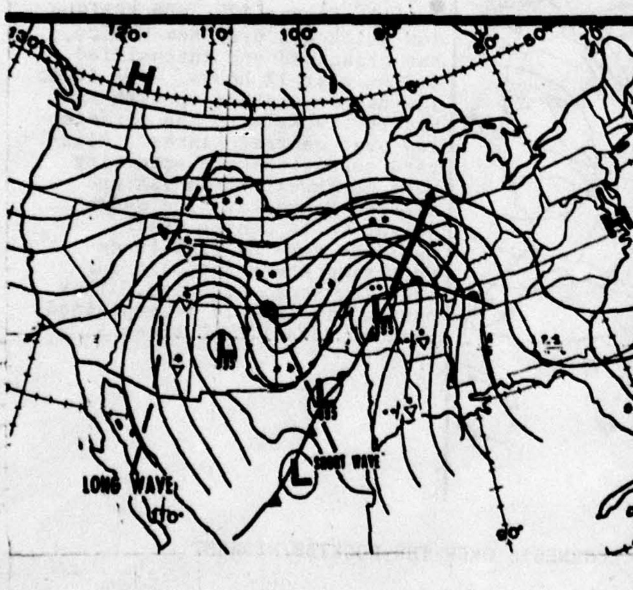

Figure 33b: 12Z 3 Jan 1971

The surface pattern in Figure 33 occurs when high pressure ridges build over the Pacific Northwest and western Canada and extend into the upper Midwest. At the 500mb level, the Pacific ridge is building off the West Coast and short wave troughs/lows move southeastward towards Arizona. The strong upper level flow moves these short waves rapidly towards Texas. Maritime polar cold/occluded frontal systems entering the West Coast are pushed southward, and the northern portion of these fronts weaken and dissipate as they come under the influence of the building high pressure system. These systems develop early over the southwest U.S. (closed 500mb low) and usually provide early warning of the likelihood of major storm activity (in the next 24 to 48 hours) over the central and southern areas of the Midwest. Cold air is generally present over the Midwest within the stationary ridge, and (with southwest flow aloft ahead of the approaching short wave and moist Gulf flow from the south) widespread overrunning precipitation develops. In Figure 33a, the mP cold front over California has been moving slowly southeastward (as a short wave trough deepened along the West Coast) during the previous 24 hours. By the time of this example snow has developed along the short wave over Nevada-Utah and upslope snow is developing over eastern Colorado. Rain and drizzle are developing along the stationary front in Oklahoma, as strong Gulf flow overruns the shallow airmass.

In Figure 33b, the main surface low is organizing over northeastern Oklahoma supported by the 500mb low over New Mexico. The Texas frontal low later dissipated as the front became a cold front. The 500mb trough over Arizona and Utah is becoming a long wave trough; however, the short wave over north Texas is responsible for storm development. A strong flow of Gulf moisture continues to overrun the frontal system and a large precipitation area has developed. Note the low and inverted troughing over New Mexico which is associated with the long wave trough from Montana to Arizona.

FIGURE 33: CYCLOGENESIS OVER THE SOUTHERN PLAINS

MARITIME POLAR INVERTED TROUGH SYSTEMS

The following surface patterns (Figures 34 through 36) are grouped together for one main reason. There is no apparent mP frontal system shown on the surface chart that is associated with the approaching upper trough. Instead, inverted troughing appears on the surface. Either the front has become so weak (moving into a strong high pressure area) that is has become lost in the western mountains or an upper trough has developed within zonal flow over the western U.S. and, consequently, there wasn't any associated surface front to begin with. Also, there is usually no related mP front associated with closed/cutoff lows that have been stationary over the southwest U.S. and then suddenly moved out as a short wave. The precipitation from these surface patterns often surprises Midwestern forecasters, since there is no apparent surface front (west of their locations) upon which to base a forecast. There are certain features to look for and, keeping in mind what was covered in Chapter 2, early recognition of possible storm development can be achieved.

1. Inverted Troughs (Receding High Pressure: Figure 28)

Figure sequence 34 shows a typical pattern for a potential storm system (lacking only a good cold air source). In this particular example, snow occurred only over the upper Mississippi Valley and Great Lakes. The intent is to show the potential development of a major storm system. Perhaps a similar feature setup could have a cold air source with a larger snow area the result. In Figure 34a, no recognizable mP frontal system has appeared on the surface chart; however, weak inverted troughing with a closed low is present from Wyoming to New Mexico.

The 500mb trough over Utah-Arizona is the remains of a closed low which was previously stationary over central California and is now the support for the inverted trough. The closed low did not have an associated frontal system; the surface low appeared while the upper system was moving across Arizona and New Mexico. Surface parameters to watch for while tracking a surface impulse across the mountains are pressure falls and rises and areas of precipitation. Residual moisture ahead of the stationary front and the added Gulf flow are producing scattered precipitation areas over Texas and the southern plains. Within 24 hours, a storm system developed and moved to Illinois, as shown in Figure 34b. The stationary front over Texas moved northward and joined the surface low when it moved out of the southern Rockies. The 500mb short wave moved northeastward with a low center over Iowa. Precipitation became widespread over the central Midwest, but it was mostly rain, while snow occurred in the northern plains and Great Lakes.

Closed lows located over southern California and northern Mexico within a long wave trough at 500mb can remain quasi-stationary for days. Then, almost suddenly, they will begin to move out, usually with the approach of a new impulse from the Pacific Northwest. In many cases, there will not be an associated mP frontal system with these closed lows. There is, however, usually an mP and/or cP front approaching from the Pacific Northwest with the new impulse which is inducing the closed low to "kick out." As stated in Chapter 2, closed lows within the long wave 500mb trough will often move rapidly northeastward and become short waves. Usually, large areas of precipitation develop ahead of these short waves over the Midwest prior to the arrival of the new front. The eventual surface patterns that are most likely to become associated with these short waves (closed lows) over the Midwest are:

- Approaching mP front (and sometimes a cP cold front) moving southward from Alaska/Canada associated with the new 500mb short wave which "kicked out" the closed low.

- Cyclogenesis along a stationary front in the Gulf of Mexico and/or the southern Texas-Louisiana area. The upper level closed low would lend support to development of a frontal wave in these areas as it moves northeastward across the central Midwest as a short wave.

In Figure 35a, the short wave low shown in the vicinity of El Paso (ELP), Texas had been over northern Baja California 12 hours earlier. Note that there is no associated mP frontal system with this short wave. The thermal low over Mexico should not be considered to be the main surface feature. This thermal low is occasionally mistakenly identified as being or becoming the main feature at the surface because of the intensification and pressure drops that occur in the vicinity of the low during the time period when the upper-level short wave trough or closed low is moving

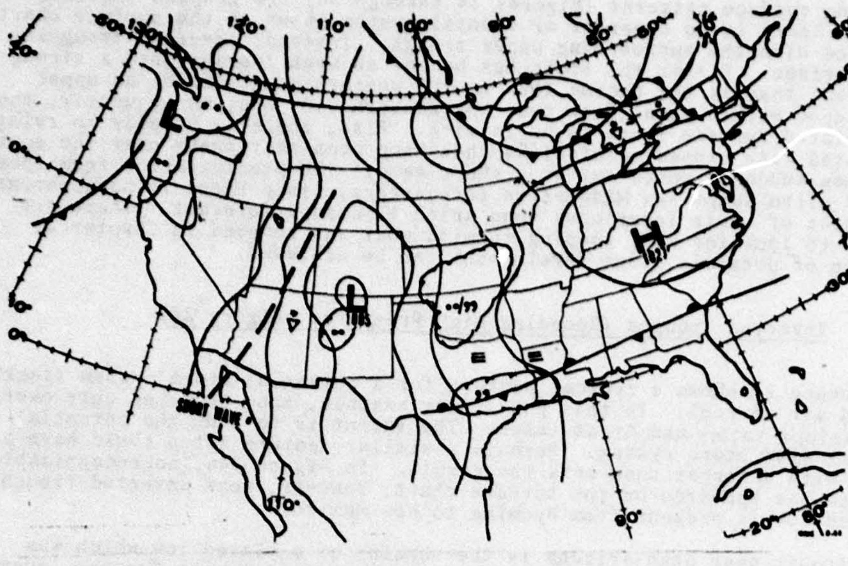

Figure 34a: 12Z 29 Dec 1971

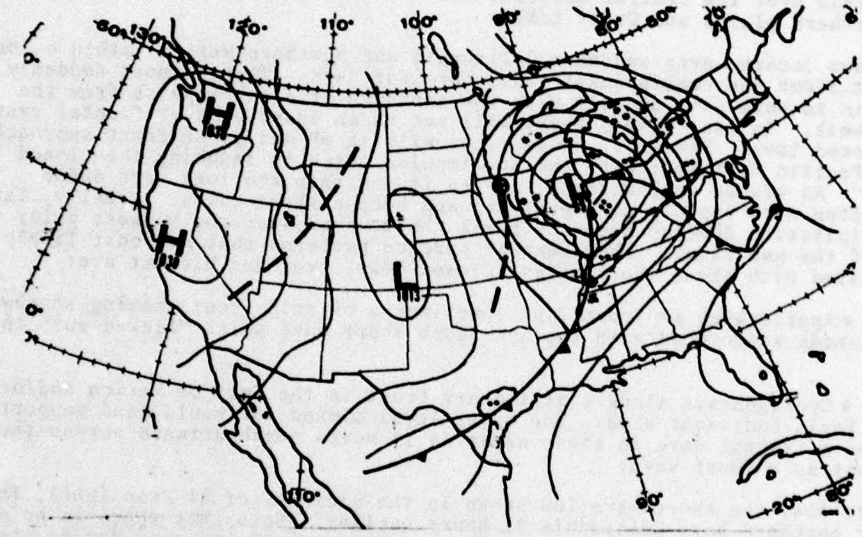

Figure 34b: 12Z 30 Dec 1971

EXAMPLE 1 - MARITIME POLAR INVERTED TROUGH - RECEDING HIGH

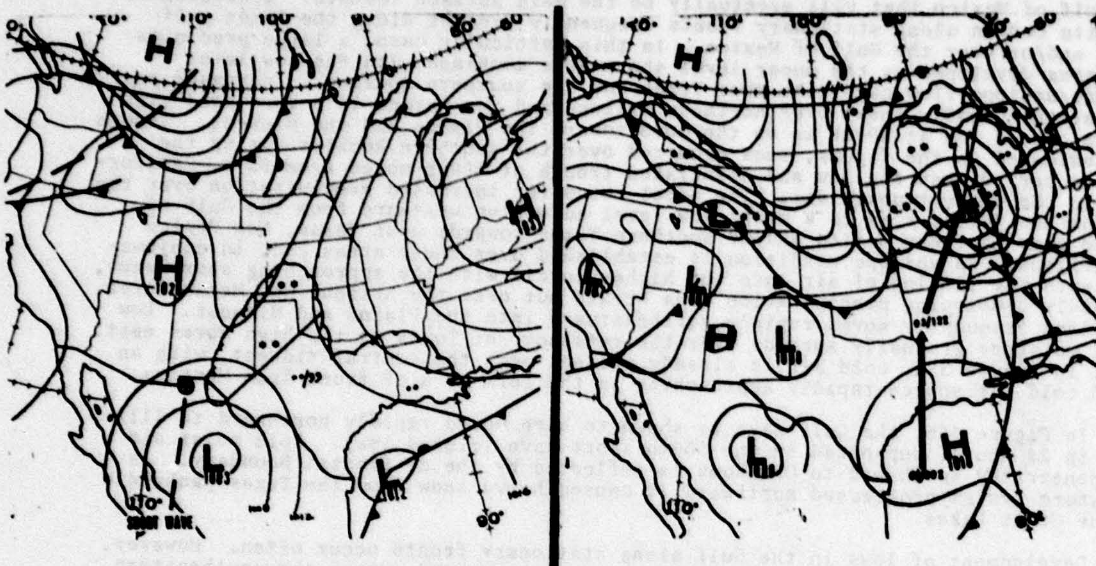

Figure 35a: 00Z 3 Jan 1973 **Figure 35b: 00Z 4 Jan 1973**

EXAMPLE 2: MARITIME POLAR INVERTED TROUGH - RECEDING HIGH

Figure 36a: 12Z 21 Feb 1971 **Figure 36b: 12Z 22 Feb 1971**

MARITIME POLAR INVERTED TROUGH - PREVAILING HIGH

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across New Mexico and west Texas. It is the wave shown on the front over the western Gulf of Mexico that will eventually be the main surface feature. Cyclogenesis is quite common along stationary fronts frequently present along the Texas gulf coast and/or over the Gulf of Mexico. In this particular case, a large precipitation area developed as the upper level short wave combined with the low level onshore/upslope flow condition over Texas and the southern Rockies. Increased precipitation (usually snow) over northern Arizona and New Mexico is a very good sign that a closed low at 500mb is on the move toward the Plains and the Midwest. Though not indicated in the figure, snow occurred over the southern Rockies during the 12-hour period when the low and associated trough at 500mb moved from Baja, California, to the present positions. The ideal setup for increased precipitation over the Arizona-New Mexico area is a moist low level advection westward from the Gulf of Mexico over northern Mexico and/or southern Texas towards west Texas, New Mexico and Arizona. An upslope condition is established over these areas and, in conjunction with the lifting of air into the higher levels with the approaching short wave, a rapidly developing precipitation area breaks out over the Arizona-New Mexico area. This area frequently moves rapidly northeastward into the Plains and Midwest. Low level moisture gradually spreads over the remainder of Texas as the high moves east. Also, in Figure 35a, cold air is already present over the central Midwest, with an added cold air source rapidly approaching in the form of a cP front from Montana.

In Figure 35b, the Gulf wave is shown to have moved rapidly northward to Illinois in 24 hours, supported by the 500mb short wave (closed low). Cold polar air has penetrated southward to Oklahoma as reflected by the cP frontal boundary. As the storm system progressed northward it caused heavy snow from the Texas panhandle to the Great Lakes.

Development of lows in the Gulf along stationary fronts occur often. However, as a general rule, these lows will move east northeastward across the southeastern states. Normally, the central and upper Midwest regions do not receive significant precipitation from systems developing over southeastern Texas and the Gulf unless there is an associated inverted trough extending northward from these waves over the Plains and the Midwest. Be on the lookout for these inverted troughs. Frontal waves across southern Texas and the Gulf of Mexico should not be ignored by central Midwestern locations when closed lows from the southwestern U.S. are moving north or northeastward toward the Midwest as short waves.

2. Inverted Troughs, (High Pressure Over Northern U.S.: Figure 29)

This pattern is established when mP frontal systems from the Pacific become so weak under the dominance of high pressure that their frontal characteristics are lost over the mountains. The pressure pattern becomes an inverted trough feature as it approaches the southern and central Rockies. In many cases, the associated upper trough continues eastward and deepens. Major snow storms developing within the inverted trough over Texas and/or Oklahoma are not uncommon when the upper trough/low bottoms out over New Mexico and moves across the central Midwest.

In Figure 36a, a low is organizing along the stationary front in Texas. A weakening mP frontal system which was over Arizona 24 hours earlier, is represented by the inverted trough extending northward from the Texas low to Oklahoma. The inverted trough over the New Mexico-Utah area is a reflection of the long wave trough and surface discontinuity of colder polar air pushing southward through Colorado and New Mexico. The 500mb low over New Mexico has reached its lowest position at the base of the trough and is moving easterly. Moderate to heavy snow is falling over the Rockies and western plains.

In Figure 36b, the 500mb low has shifted to a northeast course towards Kansas. The surface low developed rapidly along the Texas frontal system, moved northward in response to the upper low and had reached the occluded stage within 24 hours. Moderate snowfall continues over the central plains and later moves into the Great Lakes.

STORM SYSTEMS APPROACHING MIDWEST FROM THE NORTHWEST

So far in this chapter, it has been shown that systems having the potential to become snowstorms usually approach the Midwest from the west and/or south. There is another pattern which will produce moderate to heavy snowfalls over the Midwest

and for which the relationship between the surface and upper air features are somewhat different from what has been discussed so far. Specifically, there is usually a persistent continental polar or arctic air mass prevailing over Canada extending southward into the central Midwest throughout the snowfall period. The snowfall area develops within the cold air over western Canada as moist Pacific air flows over the top of the cold air dome. In this pattern, the trigger is the presence of a developing (strong) short wave over western Canada, usually with a low center, which gradually moves southeasterly towards the Midwest. In these discussions, all references to polar or arctic air will be termed Polar. The following features have been noted with this pattern:

UPPER AIR: The mean long-wave trough is oriented north-south across the central Midwest. The Pacific ridge extends inland over the western U.S. - Canada area and shifts the short wave track from the coastal area of western Canada further to the east. Consequently, developing short waves will move southeasterly across the northern and central Rockies and bottom out within the mean long wave trough across the central Midwest. The associated Pacific moisture spreads southeastward over the cold polar air, resulting in an increasingly larger snowfall area over the western plains. Also, as the upper wind flow backs towards the west with the approach of the short wave, an excellent overrunning situation develops over the Midwest, resulting in an increased snow area. At the 300mb level, the jet's mean flow extends from the Pacific northwest across the central Rockies to the southern plains where it turns to the northeast within the bottom of the long wave trough.

SURFACE: As pointed out earlier, strong polar air masses exist over central Canada and the Midwest with this pattern. The main frontal system is the polar front (often stationary) that appears along the lee side of the Rockies from western Canada to New Mexico then continues eastward across the southern plains as the leading edge of polar air. There may or may not be a significant low along this front during the early development of the short wave; strong surface low development is often hindered by the dominance of high pressure over the Midwest. If a normal surface pattern existed over the Midwest (receding high) with the approach of a short wave from the northwest, a low pressure system would be reflected on the surface over the Midwest. Also, it should be mentioned here that low development along the polar stationary front over southwestern Canada (Alberta low) generally moves east to southeast towards the Great Lakes (supported by an easterly moving short wave). Alberta lows generally do not pose a threat of significant snowfall to central and southern Midwest locations; however, upper Midwest locations have frequently received significant snowfalls. There occasionally are situations when Alberta lows will move southward along the stationary polar front to the lee of the Rockies, producing moderate snowfalls over the Midwest. The associated short wave moves southerly rather than easterly. An organized low should appear along the polar front, usually over the southern plains, and move briefly eastward while the 500mb short wave bottoms out within the long wave trough. The entire system intensifies and shifts northeastward as the short wave begins to turn northeastward. Figures 37 and 38, in 24 hour periods, show two examples of this particular pattern. In both cases, strong polar highs are prevailing over the Midwest as these snow areas move southeastward.

Care should be taken in determining if this pattern is developing. Light snowfall areas ($\lesssim$ 2") occur frequently within the cold polar air mass over the western and northern sections of the Midwest and into Canada, especially along the lee slopes of the Rockies (upslope). These areas expand over the upper Midwest when weak impulses are moving easterly within the westerly flow. Additionally, weak waves/lows (often terrain enhanced) will also produce light snowfall areas across the western and central portions of the Plains. However, to produce the major snowstorm that we are interested in, very strong and evident upper level support must accompany the surface system.

In Figure 37a, the mean long wave trough with weak amplitude has shifted westward from the East Coast. A west to east flow is occurring over the central and eastern U.S. A new 500mb short wave, which was located over the Yukon area 24 hours earlier, has moved southeastward to southern Alberta and British Columbia. The trough extends southward into eastern Washington and Oregon, as shown. The Pacific ridge at 500mb is located off the West Coast and extends northward into Alaska. At the surface, the cP front is moving southward supported by a 1057mb high over the Yukon area. An area of continuous snow is developing within the cold air over southern Canada east of the short wave and has spread into northern Montana and western North Dakota. Low level gulf moisture is increasing along and south of the warm front in southern Texas.

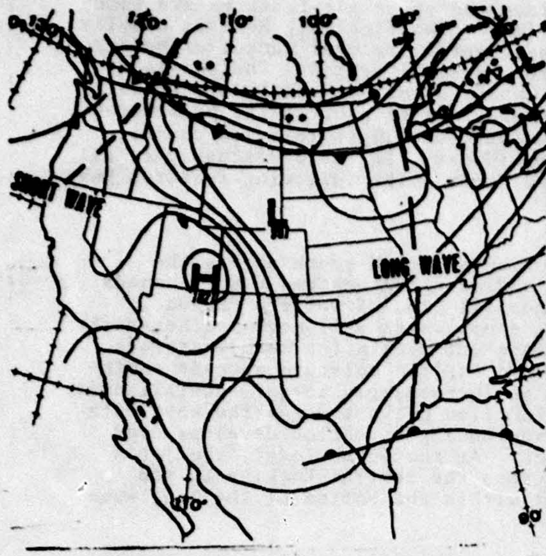


Figure 37a: 12Z 9 Jan 1963

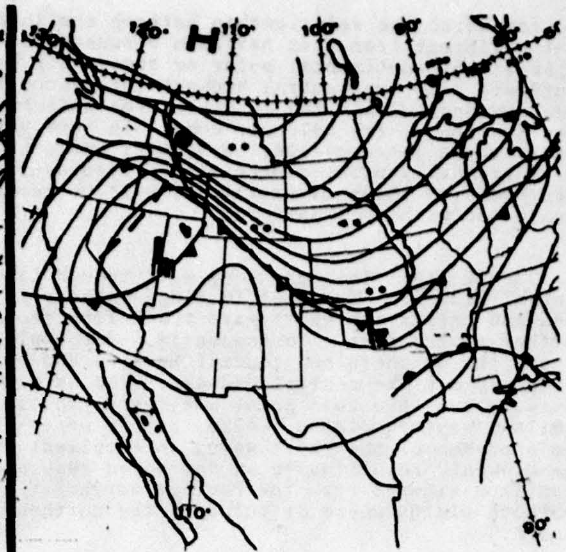


Figure 37b: 12Z 10 Jan 1963

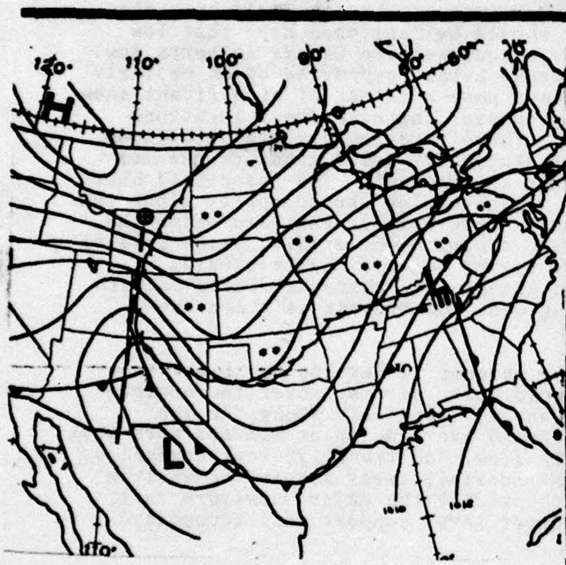


Figure 37c: 12Z 11 Jan 1963

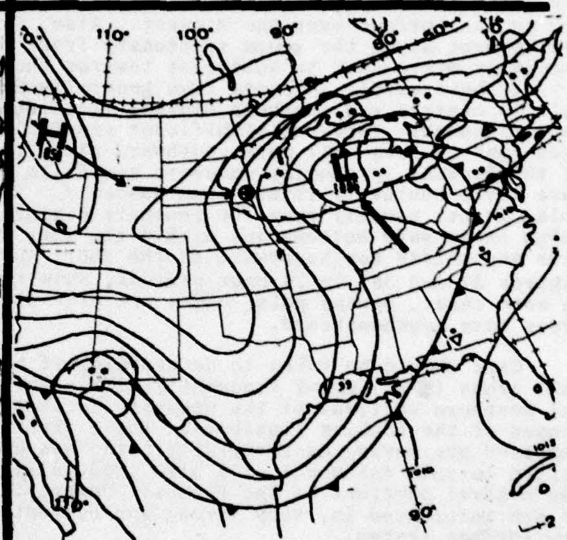


Figure 37d: 12Z 12 Jan 1963

STORM SYSTEMS APPROACHING FROM THE NORTHWEST

EXAMPLE 1

In Figure 37b, the 500mb short wave has moved slowly southeastward to the western Montana-northern Idaho area and has intensified. A low appears over western Montana and should continue southeasterly. The 500mb flow over the Midwest is beginning to back to the west with further shifting westward by the long wave trough. At the surface, the cP front is pushing into the central Midwest as the high (1052mb) over southern Yukon continues southward. The snow area has expanded as it moves southeastward behind the polar cold front. A low which moved along the front from the lee slopes of the Rockies now appears along the polar front in Oklahoma. A Pacific cold front is moving southeasterly across Utah and Nevada in the warmer mP air. Usually, Pacific fronts, sliding southeasterly to the west of a cP outbreak under northwest flow aloft (as shown in figure 37b), weaken when they reach the New Mexico-west Texas area. (Normally, the polar airmass has moved deep into Texas by that time and will dampen the Pacific front. Main cyclogenesis often occurs further eastward along the cP front due to an influx of gulf air producing a strong discontinuity between these air masses.) Weak Pacific fronts (as shown in Figure 37b) will, however, serve as a trigger for cyclogenesis along the cP front over the New Mexico, west Texas and northern Mexico area when an upper trough/low is approaching these areas from the west. This setup, would frequently fall into the category of patterns described earlier in this chapter.

In Figure 37c, the upper trough has intensified considerably and is developing into a long wave feature over the Rockies. The upper flow over the Midwest has shifted to the southwest and, with a cold northerly flow in the lower levels, an excellent overrunning situation has developed. At the surface, the cP cold front has pushed deep into Texas. The frontal low that was over Oklahoma has moved up the front to Kentucky. The cP front has now pushed all the way through Texas. The warm front had joined the system over the lower Mississippi valley and is spreading gulf air over the cold air in the Ohio Valley area. The snow area is extensive over the central and upper Midwest and is spreading towards the Great Lakes; however, note that the snow (and precipitation, in general) abruptly ends at the Oklahoma - Texas border.

Twenty-four hours later (shown in Figure 37d) the 500mb low has bottomed out in the vicinity of Sioux City, Iowa (SUX); it later shifted northeastward. The associated surface low over Kentucky, in essence, split. The secondary center continued to move northeastward to southern Pennsylvania (the triple point), while the primary low moved northward. It is shown located over eastern Wisconsin and stacking ideally with the 500mb low. The arrows on this figure denote previous 500mb low and surface low tracks. The snow area in Figure 37c shifted northeastward towards the Great Lakes and did not affect Texas or Arkansas, as the Pacific front was forced into Mexico and the low center previously near El Paso filled.

The storm that is shown in Figure sequence 38a through 38d occurred over the Midwest during the period November 24 - 27 1975. It is an interesting case study where low formation along the stationary cP front over Alberta, Canada, moved southerly and affected a large area of the Midwest. The sequence of figures closely resembles the general features shown in the previous sequence, except for the main surface low track.

In Figure 38a, the 500mb mean long wave trough extends north-south over the Midwest and the Pacific ridge extends inland over the western U.S. A high cell is located off the northern California coast. The segment of the short wave that appears over British Columbia extends northeastward to a low pressure area over northern Alberta. This short wave developed off the southeastern coast of Alaska 12 hours earlier. The jet stream position lies across the Gulf of Alaska, swings southeastward across southern British Columbia and continues southeastward over the Rockies to New Mexico then turns easterly at the bottom of the long wave trough. A 110 kt jet maximum is located from the Gulf of Alaska to southern British Columbia.

At the surface, the frontal wave over Missouri developed earlier in southeastern Nebraska along the stationary cP front. The frontal low that appears

Figure 38a: 12Z 24 Nov 1975

Figure 38b: 12Z 25 Nov 1975

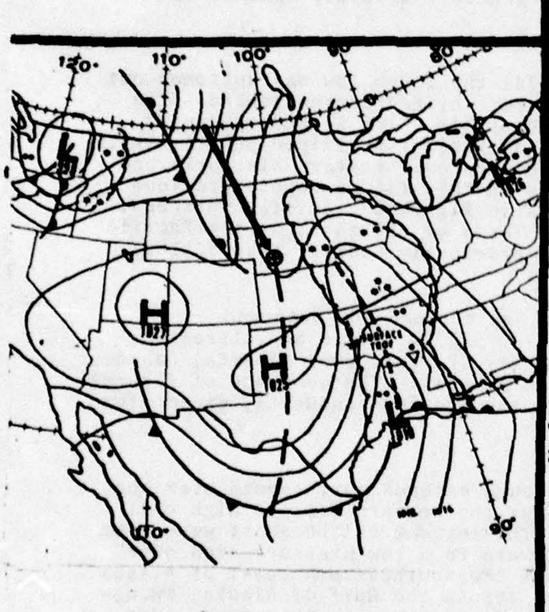


Figure 38c: 12Z 26 Nov 1975

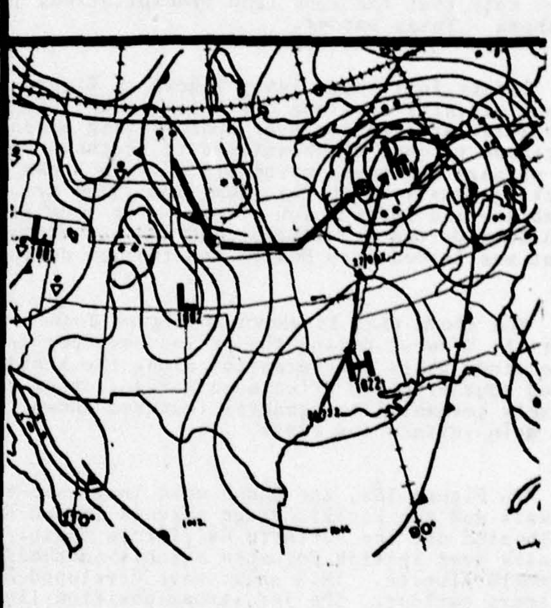


Figure 38d: 12Z 27 Nov 1975

STORM SYSTEMS APPROACHING FROM THE NORTHWEST

EXAMPLE 2

over northern Montana developed over southern Alberta as the short wave approached from the northwest. A snow area is increasing within the cold air along the stationary front over Alberta and northern Montana, as moist Pacific air ahead of the short wave travels over the colder air. The cold front entering the Washington coast is really cP in nature because a building high off the British Columbia coast is drawing cP air southward.

In Figure 38b, the 500mb short wave, caught in the downstream flow from the Pacific ridge, continues southeastward through the Rockies. The 500mb low, which was over northern Alberta earlier, has dropped southward to the Montana-North Dakota border. (Note: The 500mb height fall centers would be very helpful in determining the track that the Alberta low will take over the next 12 to 24 hours.)

At the surface, the cold air over Washington merged with the polar air mass over southern Canada, resulting in an extensive high pressure area from the West Coast to the Great Lakes. The low over Montana dropped rapidly southward along the stationary front to the lee side of the Rockies and deepened 18mb. The snow area has expanded within the cold air due to the continued development of the short wave. No Gulf moisture is evident yet.

In Figure 38c, the short wave continues southeastward to the western plains. The 500mb low center has dropped even further southward and is now located over western Nebraska; the low is beginning to approach the long wave trough over the central U.S. and should soon reach its lowest position.

An inverted trough is indicated at the surface from the low center northward to eastern Nebraska. The inverted trough possesses frontal characteristics in that it separates drier polar air from the warmer, more moist flow from the Gulf of Mexico. The approach of the short wave trough also supports continuation of this inverted trough. The inverted trough persisted and is subsequently identified as an occluded frontal system. Note the great distance between the surface low and the 500mb low due to the shallowness of the polar air mass. The surface low should soon begin to swing north-northeastward along the inverted trough. Development of inverted troughs topside of low pressure systems as shown in Figure 38c is a reliable sign that the upper trough is still intensifying and that the upper system is probably turning northeastward. Low centers generally will travel up along the inverted trough during northeastward movement of the trough. Gulf moisture first appeared on the scene at 2200Z, Nov 25 (14 hours earlier), over southeastern Texas and quickly spread northward ahead of the approaching low. resulting in the additional moisture source. Rain developed from the Gulf Coast northward. With the addition of gulf moisture, heavy snow is reported over Missouri and western Illinois.

In Figure 38d, the 500mb low bottomed out over northern Missouri at 27/0000Z and turned northeastward to Lake Michigan. The surface low over southeast Texas responded to the upper low's northeasterly shift and was located over eastern Michigan in 24 hours. Heavy snows occurred over Missouri, Iowa, Illinois and Indiana and northward ahead of the low as it moved northward. (Further discussion pertaining to this particular storm will be presented in the next chapter.)

SUMMARY

In summary, it can be seen that there are many synoptic patterns that can produce significant snowfalls over the central United States. The favorite area for storm development is in the south and central Rockies; however, forecasters should closely watch system development over the northern Rockies and the Gulf of Mexico. These areas, also, are potential breeding grounds for Midwest snowstorms under the right upper flow patterns. The dominance of surface high pressure systems across the central and upper sections of the U.S. during storm formation often presents a problem in deciding which direction to steer the storm. Primary considerations for continued development and steering should be concentrated within the upper levels. For that reason, in the next chapter, discussion pertaining to the identification, development and steering of the main surface low system as it crosses the central plains will be presented.

CHAPTER 5

THE MAIN SURFACE LOW: IDENTIFICATION, INTENSIFICATION, AND MOVEMENT

INTRODUCTION

In this chapter, we will tie together the developments at the various levels that take place to produce major snowstorms over the Midwest. Emphasis will be placed on the relation of events at 500mb to those at the surface. Thus, the main concept will be the relationship that is found to exist between the movement and tendencies of the 500mb height fall center, the 500mb low/trough, and the main surface low. In the discussion of correlation between these upper air and surface features, the primary goal is to help you, the forecaster, more rapidly and more precisely identify the area to be affected by the storm and more clearly determine the most probable area to receive heavy snowfall.

Using more or less the same order of discussion found in the previous chapter, the presentation will again be divided into two primary situations of (I) the high pressure system which is receding eastward from the Midwest and (II) the high pressure system that prevails over the Midwest for considerable periods of time. In each instance, the discussion will key upon identification of the main surface low. Since the main surface low can develop from the lee-side low or troughing and from cyclogenesis along a front or an inverted trough, a variety of case study examples having one of these characteristics at the surface are discussed.

In the final section (III) entitled: Special Cases, for lack of a better name, discussion will include (1) the storm system that develops to the northwest of the central U.S. and (2) examples of precipitation development associated with storm development over the Great Plains. In the first part of the section, the purpose in mind is to show forecasters that the occasional heavy snowfall occurrences that develop when the upper level low is approaching from the northwest can be more readily followed by tracking the 500mb height fall center. The discussion concerning precipitation development in the final portion of the chapter is included to emphasize the importance of remaining ever alert and making use of all available data. The examples to be shown and discussed relate to situations which found the Plains virtually free of any precipitation only to be found a short twelve hours later under the influence of a full scale storm.

DEVELOPMENT AND STEERING OF SYSTEM

Generally speaking, available current and outlook advisories concerning potential storm development provide ample warning of the imminence of a snowstorm. Sometimes, however, the snowfall indicated by these forecasts does not materialize with the timing or within the heavy snow forecast areas that have been designated, while other areas not expected to have a significant snowfall end up receiving the brunt of the storm. There are, of course, a variety of reasons for these forecast errors. However, through the years two reasons have produced the majority of the erroneous forecasts. Quite often, the progs have shown a tendency to move the upper level area of cyclogenesis southeastward or eastward as it comes out of the southern Rockies rather than anticipating the bottoming out covered in a previous chapter of this technical note. In the process, the track of the storm is improperly forecast to also move to the southeast or east rather than turning northeastward. More often, though, we are found guilty of designating the wrong surface low as the main surface feature. Each storm organizing over the southern Rockies and south central U.S. requires considerable attention to ensure that proper identification and steering of the storm is guaranteed.

Figures 39, 40, and 41 are offered at this time to emphasize the problem at hand. In each of these figures are shown actual surface features approximately 24 hours prior to onset of heavy snowfall over areas of the Midwest. As you can see, it is not at all uncommon for several low pressure centers to appear within the storm development area. In each figure an arrow is used to indicate the surface center or the low pressure development area which eventually will become the main feature. Determining which surface low to watch will, hopefully, be an easier task by the time the reader has completed this chapter. Every variety of major storm situation known to have occurred over the past dozen or so years has been examined and included in one of the examples of case studies that are to be found in this chapter.

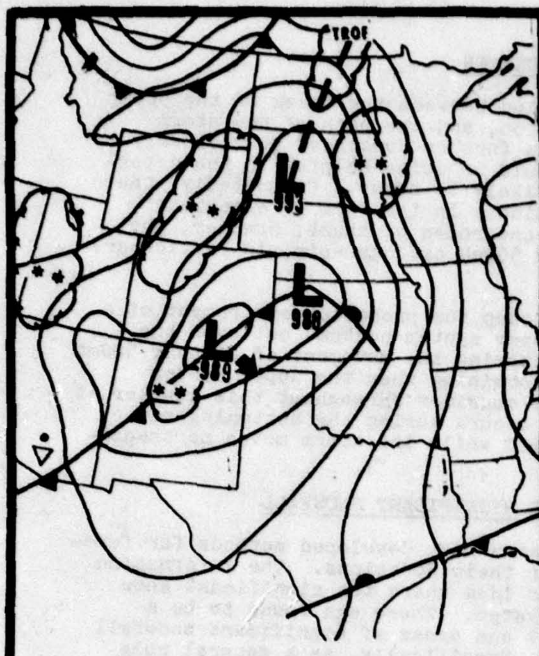


Figure 39: 12Z 9 Jan 1975

Figure 40: 15Z 4 Mar 1976

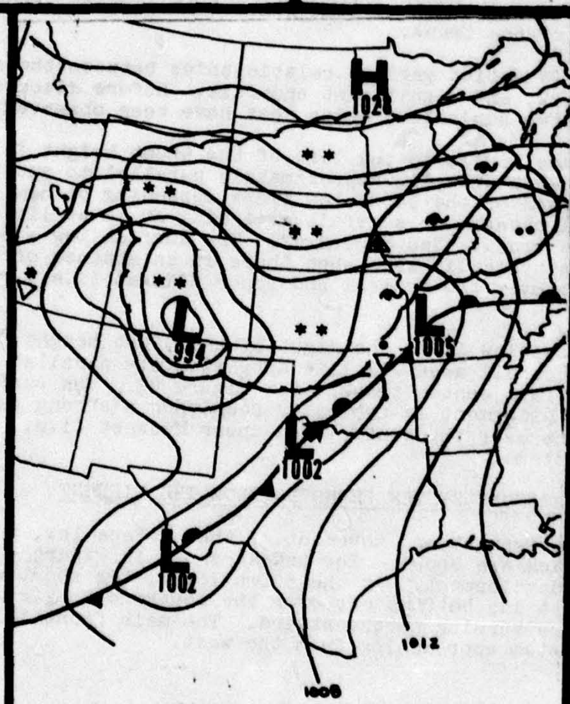


Figure 41: 00Z 21 Jan 1973

IDENTIFICATION OF THE MAIN SURFACE LOW

500MB HEIGHT FALL CENTER

As discussed previously, a strong correlation between the track of the 500mb height fall center and development, intensification, and the path of the storm system at the surface was found to exist. It was further concluded that closely following the track of the height fall center could be quite helpful in the determination of where heavy snowfall would be most likely to occur. Undoubtedly, there are several very useful forecasting methods available in the form of excellent facsimile products and worthwhile local studies and rules of thumb; however, the value of 500mb data (and height fall and related 500mb cyclogenesis, in particular) as a forecast tool cannot be overemphasized.

To briefly review them, the most typical setup for probable development of a snowstorm in the central U.S. occurs when the upper system bottoms out over the western and/or northern sections of Texas. Monitoring the movement of 12-hour 500mb height fall centers would be very helpful in determining when the upper system bottoms out within the trough. Another point to consider throughout this chapter is that minimum, if any, intensification generally occurs during the bottoming out period with maximum storm intensification attained while the storm moves northeasterly.

THE 500MB HEIGHT FALL CENTER AND SIGNIFICANT SNOWFALL

Many weather units lying within the snow area have developed methods for forecasting the probability of snow versus rain over their locations. The information to be presented here is general and will give an idea where the significant snow area will be located in relation to the storm system. There was found to be a relationship between the 500mb height fall track and areas of significant snowfall based on data from previous Midwest snowstorms. Specifically, as a general rule derived from case studies from 1952 through 1975, the division line between frozen and liquid precipitation is the track of the height fall center. Snow occurs to the left (cold air side) of the track.

Figures 42, 43 and 44 depict various relationships between the surface low, the 500mb height fall track, and significant snowfall. Before discussing these three figures, there are two subjective rules that have been observed:

* When the surface low is to the left of the 500mb height fall center track, the significant snowfall area will lie approximately parallel to and to the left of either the surface low track or the 500mb low track depending on how cold the storm system is. In nearly all cases, the snowfall area will at least lie along and parallel to the 500mb low track. See Figure 42. The surface low - 500mb height fall center track alignment is typically seen when there is an absence of a strong surface high pressure system over the central and upper Midwest (i.e., receding surface high pressure pattern).

* When the surface low is to the right of the 500mb height fall center track, the significant snowfall area will lie approximately parallel to and to the left of the 500mb height fall center track. See Figure 43. The surface low-500mb height fall center track alignment is typically seen when a strong surface high pressure system is present over the central and upper Midwest (i.e., prevailing surface high pressure system).

HIGH PRESSURE SYSTEM RECEDING FROM THE MIDWEST

In Figure 42, the alignment and movement of the surface low, the 500mb low and the 500mb height fall track are shown. The tracks shown in Figure 42 depict the typical setup for storm development. At the 500mb level, the short wave/low is moving towards the Midwest and bottoms out over the southern Rockies/western and northern Texas area before turning northeastward. The main frontal low would likely be along a mP frontal system approaching from the west.

RELATIONSHIPS BETWEEN THE SURFACE LOW, THE 500MB HEIGHT FALL CENTER AND HEAVY SNOWFALL

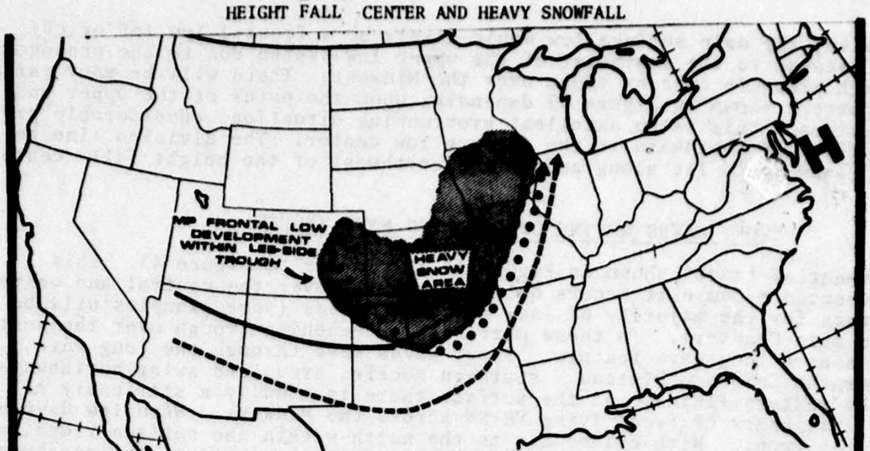


Figure 42: Receding High

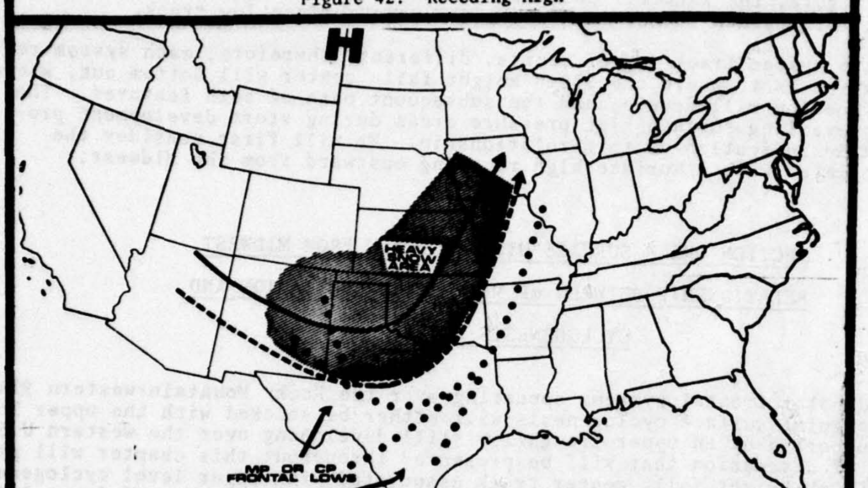


Figure 43: Prevailing High

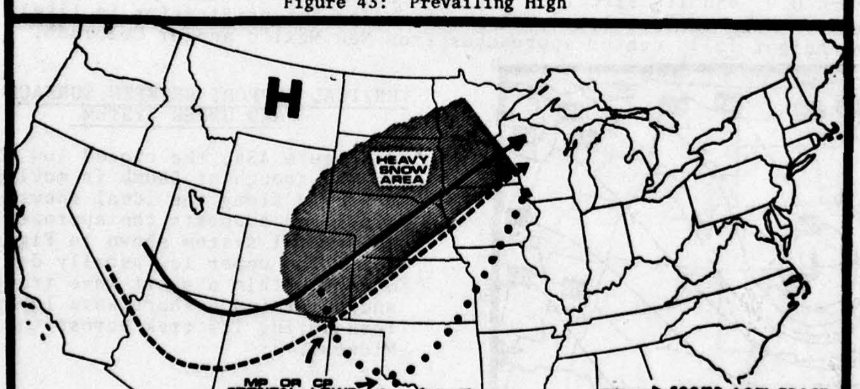


Figure 44: Short Wave within a Long Wave Trough

HIGH PRESSURE PREVAILING OVER THE MIDWEST

In Figure 43, the main surface low would likely be a frontal low (mP or cP) located some distance to the southeast of the upper low system due to the presence of a strong high pressure area or ridge over the Midwest. There will be many variations to the pattern shown in Figure 43 depending upon the paths of the upper and surface low systems. This is an excellent overrunning situation; considerable precipitation would occur southward to the surface low center. The division line between rain and snow would lie along and to the northwest of the height fall center track.

SHORT WAVES MOVING OUT OF LONG WAVE TROUGH

The alignment of tracks shown in Figure 44 is similar to Figure 43. This pattern is presented because it occurs quite frequently over the central and western U.S. and accounts for the majority of snow forecast misses (some examples will be shown later in this Chapter). In these patterns, a deepening trough over the western U.S. exists as a long wave feature. Short waves move through the long wave, bottom out over the Colorado Plateau - southern Rockies area, and swing northeastward across the western Plains. At the surface there is usually a stationary mP or a modified stationary cP front lying NE-SW across the Midwest. Main low development is along the front. With colder air to the north within the surface ridge, as shown in the figure, the snowfall path will usually fall along and to the northwest of the height fall track rather than along the main surface low track.

Each storm system track is, of course, different; therefore, each system requires evaluation as to where the 500mb height fall center will bottom out, where the main surface low will develop and the subsequent path of both features. The location of prevailing surface high pressure areas during storm development provides a reliable indication of this relationship. We will first consider the patterns associated with a surface high receding eastward from the Midwest.

SECTION ONE - SURFACE HIGH RECEDING FROM MIDWEST

RELATIONSHIP BETWEEN mP MAIN LOW ORGANIZATION AND CYCLOGENESIS ALOFT

Maritime polar frontal systems appearing over the Rocky Mountain-western Plains area and undergoing surface cyclogenesis will either be stacked with the upper low or will be supported by an upper trough/low still developing over the western U.S. The majority of discussion that will be presented throughout this chapter will pertain to the 500mb height fall center track associated with upper level cyclogenesis over the western U.S. and its effect on the development and movement of frontal lows over the Midwest. Main surface low development and/or intensification is likely when the 500mb height fall center approaches from New Mexico and/or Colorado.

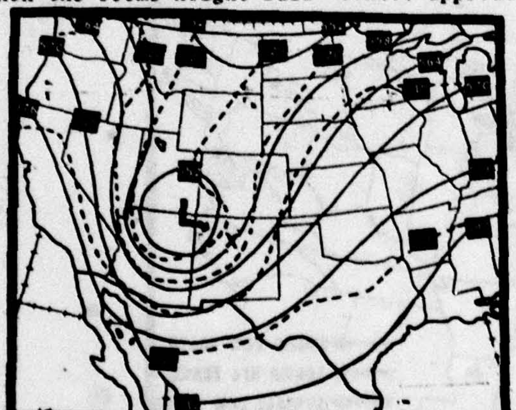


Figure 45a: 500mb, 00Z 3 Dec 1973

VERTICAL SUPPORT BETWEEN SURFACE AND UPPER SYSTEM

In Figure 45a, the closed low within the trough at 500mb is moving easterly along the ideal snowstorm track and supports the approaching mP frontal system shown in Figure 45b. The upper low usually develops within a short wave trough and maintains a short wave low pattern during its trek across the Midwest.

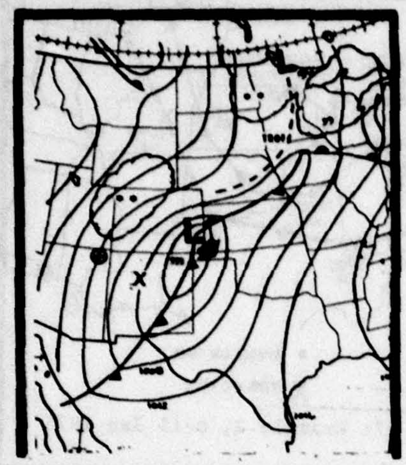


Figure 45b: Surface, 00Z 3 Dec 1973

Associated surface low organization usually occurs along the mP frontal system within the lee-side trough and the main low is not hard to identify once it organizes over the western plains. A strong low level jet and Gulf stratus occur with this setup.

NOTE: ***In this and all subsequent related*** **figures the respective main features will be identified as follows:**

Feature	**Ident.**
500mb low and track	
500mb Ht fall center/track	
Surface Low and track	

SURFACE FEATURES

The appearance of one or more surface lows (frontal and/or non-frontal) within the lee side trough occurs often with the surface high receding eastward. The identification and steering of the main surface low in relation to the approaching 500mb height fall center will be presented in the following examples. Also, recognition of changes in frontal structures, as these systems move into the western plains, will be discussed. These frontal changes are sometimes indicators that a storm system is developing.

LEE-SIDE LOWS (MAIN LOW) DEVELOPMENT AND MOVEMENT

It was mentioned in Chapter 3, 850mb level, that eventually the ***lee-side low*** **becomes the major low when cyclogenesis aloft occurs to the west or southwest of the Rockies, except when a strong high is prevailing over the Midwest. The lee-side low is established from either an organized low moving into the lee-side trough from the western U. S. or a low developing within the lee-side trough or a combination thereof.**

There appears to be a definite relationship between the movement of this lee-side low and the movement of the 500mb height fall center as upper level support for the developing storm system as it moves out of the southern Rockies. Lee-side lows generally move southeastward and often fill (excluding diurnal falls) during the period when the upper system is bottoming out within the trough. In Chapter 2, it was shown that magnitude of 500mb height fall will generally decrease or remain unchanged during bottoming out; the surface system usually fills during this same period. Figures 46, 47 and 48 show the relationship between the surface low and the 500mb height fall center. In each example, the central pressure of the main surface low and the central height fall value are shown in twelve-hour increments, as are their respective tracks.

In Figure 46, the lee-side low has become the main low, as the frontal low over Nevada dissipated. Sometimes, lows along the mP frontal system will remain behind and become stationary over the western U.S. as the mP front continues eastward. A new low will appear along the mP front when it moves into the lee-side trough. The relationship between these two tracks in Figure 46 can readily be seen. The surface low and 500mb height fall center tracks are approximately parallel, and both bottomed out over Texas. Notice that the height fall center decreased 30 meters between 03/00Z and 03/12Z; simultaneously, the surface low filled. The system subsequently moved northeastward and developed into a major storm with the 500mb ***height falls increasing after bottoming out had occurred.***

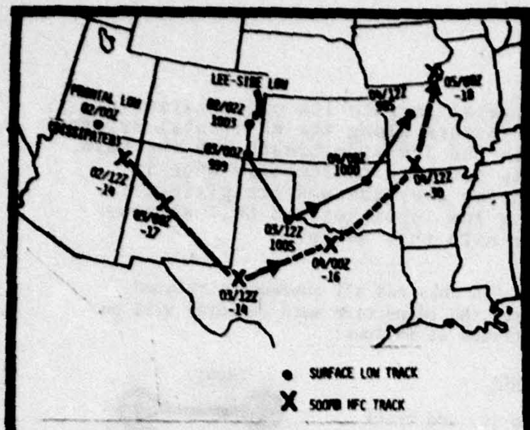


Figure 46: Example 1, 2-5 Dec 1973

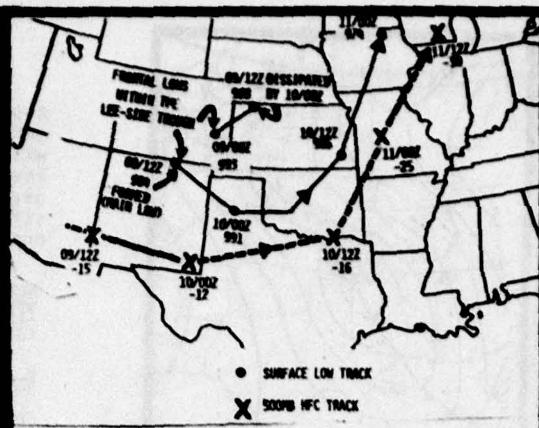


Figure 47: Example 2, 9-11 Jan 1975

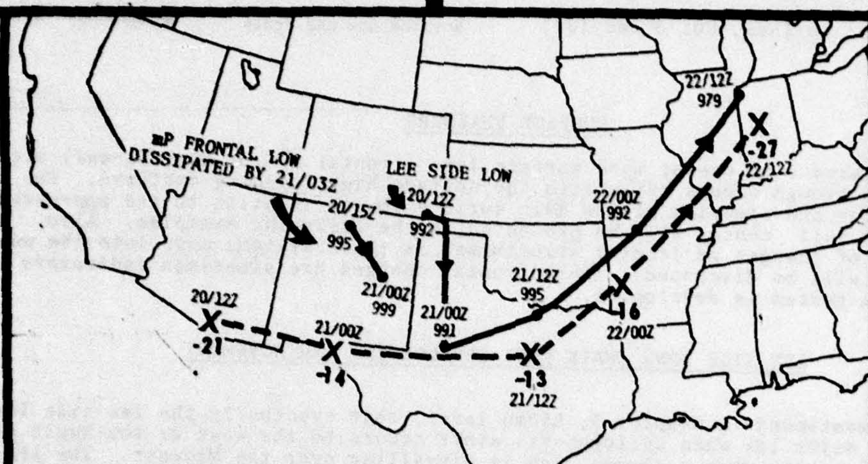


Figure 48: Example 3, 20-22 Feb 1974

MAIN SURFACE LOW/500MB HEIGHT FALLS CENTER RELATIONSHIPS

Example 47 depicts the same general pattern as shown in Figure 46. Initially, two lee-side lows were evident on the surface chart. By 09/1200Z these have both become mP frontal lows. The point to be made here is proper identification of the low which is to become the main surface low. The original lee-side low (09/00Z) moved into northwest Kansas along the mP front. The main surface low developed over southern Colorado between 09/00Z and 09/12Z along the mP front as the 500mb height fall center approached western New Mexico from northern Arizona (09/12Z). Note that this surface low and the height fall center both bottomed out and showed a decrease in central value at 10/00Z. The secondary frontal low over northwestern Kansas eventually dissipated (10/00Z). It should be most evident from this example that particular attention must be given to properly identifying the main low. A snow forecast based on the original lee-side low (located in eastern Colorado at 09/00Z) would present a forecast problem in timing the onset and determining the area likely to receive snowfall.

A third example is shown in Figure 48. The main surface low within the lee side trough moved rapidly southward between 20/12Z and 21/00Z to be properly aligned with the approaching height fall center near El Paso, Texas. Another frontal low appeared along the front by 20/15Z (in New Mexico) but dissipated

(or merged with the main low) by 21/03Z. Good agreement between the height fall center and the surface system movement after bottoming out can be seen.

Sometimes the lee-side low will prematurely move southeasterly into the western plains ahead of an approaching mP front and the associated upper low. In these cases, the surface low will "wait" over the western plains until the upper low catches up. This "waiting" period also occurs when lows form along stationary fronts and an upper system is moving towards the western plains (see discussion on page 63, Figure 57).

FRONTAL ORIENTATION/INVERTED TROUGHING

Maritime polar fronts moving from the Rocky Mountains may slow down and undergo changes in their frontal structure. Such frontal variations suggest that perhaps cyclogenesis aloft is occurring. Detecting these frontal variations, therefore, can be especially valuable during the periods between receipt of successive upper air analyses. In Figure 49, a low has organized and the mP frontal segment north of the low has become stationary, indicating the probability of backing wind flow aloft. These circumstances could give a clue to either cyclogenesis or a bottoming out of the 500mb low/impulse. The mP frontal characteristics north of the low will gradually be modified to moreso resemble cP air mass characteristics, as colder air from Canada is drawn into the low. An inverted trough is often shown on subsequent analyses, if the mP front has substantially weakened. The rain/snow division line is generally along the axis of this frontal/inverted trough line. The main surface low will usually move northeasterly along these isobaric inverted trough patterns, allowing for some easterly movement of the entire storm system.

CASE STUDIES THAT INCLUDE THE 500MB LOW TRACK

So far in this chapter, the relationship between the movement and tendency of the 500mb height fall center, the movement of the main surface low, and the probable area of heavy snow has been presented. In the three figures to follow, the 500mb low center track has been added to this relationship in order to provide a more complete picture of the storm system affecting areas of the Midwest that are associated with a receding high pressure pattern. In this respect, Figures 50 through 52 show the development and progression of major snowstorms over areas of the Midwest. Figures 50 and 51 are intended to show early and late warning of 500mb cyclogenesis associated with the storm system. Figure 52 is presented to show forecasters how a developing storm over the Rockies can change direction, leaving most of the Midwest free of snowfall. The surface low's central pressure and height fall center plus maximum height fall value shown on each 500mb chart are also included in each figure.

CYCLOGENESIS ALOFT OVER THE WESTERN U.S. - EARLY WARNING

In Figure 50, the closed 500mb low first appeared (developed) over northern Arizona at 20/12Z. The height falls, however, appeared 24 hours earlier (19/12Z) over southern Nevada, indicating the possibility of cyclogenesis within the upper trough. The main surface low developed in the lee-side trough and began moving southeasterly as the height falls center passed through Arizona and New Mexico. In this particular case, the height fall central value did not decrease during the bottoming out period in New Mexico and west Texas but (slightly) decreased earlier over Arizona. All three tracks turn northeasterly at approximately 21/1200Z. The heavy snowfall area remained to the northwest of the height fall track.

CYCLOGENESIS ALOFT OVER THE ROCKY MOUNTAINS - LATE WARNING

The storm shown in Figure 51 produced blizzard conditions over eastern Nebraska, Iowa and northward. The height fall center moved into the western U.S. at 08/12Z associated with a typical short wave trough. Continued deepening within the trough produced a closed 500mb low 36 hours later (10/00Z) over the southern

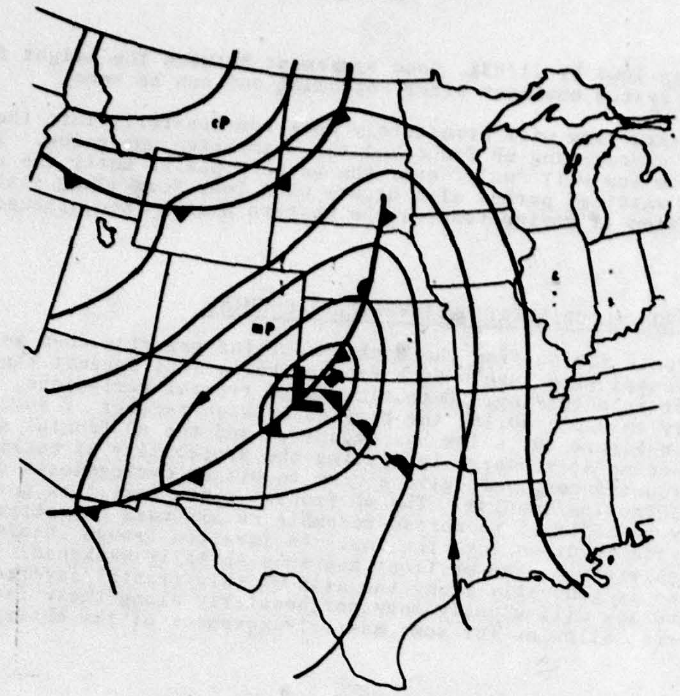


Figure 49: FRONTAL ORIENTATION/INVERTED TROUGHING

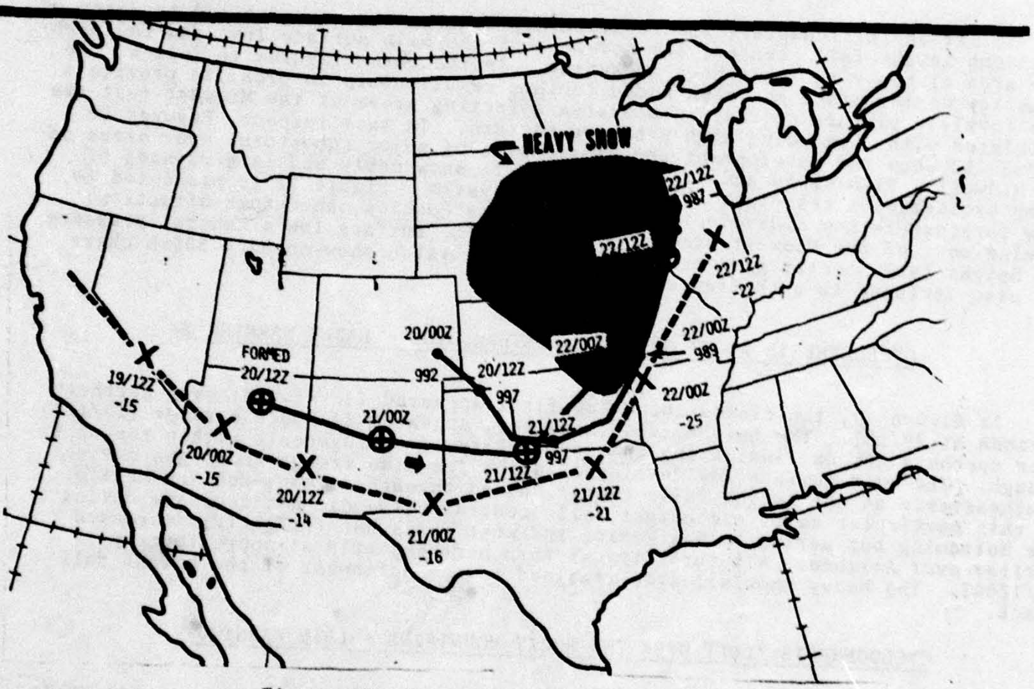


Figure 50: Composite, 19-22 Jan 1973

Rocky Mountains. Meanwhile, at the surface, the lee-side low began its southeasterly movement subsequent to 09/12Z as the height fall center moved from southern Nevada to southeastern New Mexico. Organization occurred over western Oklahoma and the system rapidly became an intense storm. Heavy snowfall occurred along and to the left of the surface low track. As this example shows, cyclogenesis aloft within a short wave trough over the Rockies can develop intense storms suddenly over the Midwest.

SHORT WAVE MOVING OUT OF A LONG WAVE TROUGH OVER THE WESTERN U.S.

This storm system affected a large area of the northern Rockies, western Nebraska and the Dakotas. The storm system shown in Figure 52 would have been similar to the preceding figures just shown; however, the short wave entering the Pacific Northwest was quite strong (-25 or greater 12-hour height falls from Washington to Arizona). It became an apparent long wave feature over the western U.S. The 500mb low and associated height fall center bottomed out early over southern Utah and Arizona instead of the New Mexico - west Texas area and moved in a straight northeasterly course towards the upper Midwest (see also Figure 17, Chapter 2). A secondary short wave impulse, marked by a cold pocket and the strong height falls area, moved rapidly southward along the West Coast into the system and was located over southern California by 01/00Z. This impulse strengthened the long wave trough and induced the 500mb low to bottom out (01/00Z) and subsequently move northeastward across the upper Midwest. The related surface low moved southward down the lee-side trough from eastern Colorado to eastern New Mexico in 24 hours. Note that the surface low and the 500mb low bottomed out at the same time (01/00Z). In this case, the height fall center bottomed out 12 hours earlier(31/12Z) and was located over northeastern Colorado by (01/00Z). This was a clue that the storm system should soon begin a northeasterly track. It was difficult to discern, with the addition of the new height fall center over California, that the original height fall center still existed over northeastern Colorado. Weakening 500mb height falls moving up a long wave trough are sometimes hard to locate when further deepening is occurring upstream to the west of the trough.

As further discussion of this case, the surface chart depicted in Figure 53 shows the analysis three hours prior to the main surface low reaching its southernmost position (01/00Z) over eastern New Mexico. The system looks like an ideal snowstorm situation for the central Plain states. The cold air source is the approaching cP high moving southerly toward the upper Plains and northern Rockies. Note the inverted troughing beginning to vaguely appear over western Nebraska and the Dakotas. This trough is likely a surface reflection of the 500mb height fall center approaching from the southwest. The surface low subsequently moved into eastern South Dakota during the next 30 hours; it moved north-northeastward, staying pretty much on the axis of the weak inverted trough.

Returning briefly to Figure 52, the main surface low organized within the lee-side trough, bottomed out in east-central New Mexico, and moved across central Kansas and eastern Nebraska. The heavy snow area, however, remained approximately parallel to and northwest of the 500mb height fall track. The entire system eventually became vertically stacked over Minnesota.

SURFACE SYSTEMS LACKING IMMEDIATE UPPER AIR SUPPORT

The second major pattern for Midwestern snowstorms under the condition of the surface high receding eastward (shown in Figure sequence 54 a & b) develops when mP fronts and merging cP fronts from Canada become stationary over the central and upper Midwest in response to upper level cyclogenesis over the western U.S. It is not uncommon for mP frontal systems from the Pacific to continue eastward across the Rockies during the period when the related upper trough is undergoing cyclogenesis. However, the eastward movement of the front usually stops just lee of the Rockies with the shifting of upper level winds to the southwest. Often, continued 500mb trough deepening, caused by another short wave and/or cold pocket moving into the short wave, changes the short wave into a long wave trough pattern with a closed low, similar to the discussion and accompanying illustration shown in Figure 52. In the cases we are now considering, however, the frontal system is already located over the Midwest during cyclogenesis over the western U.S. The 500mb height fall centers often bottom out over the Arizona-New Mexico area and move northeasterly across the western plains.

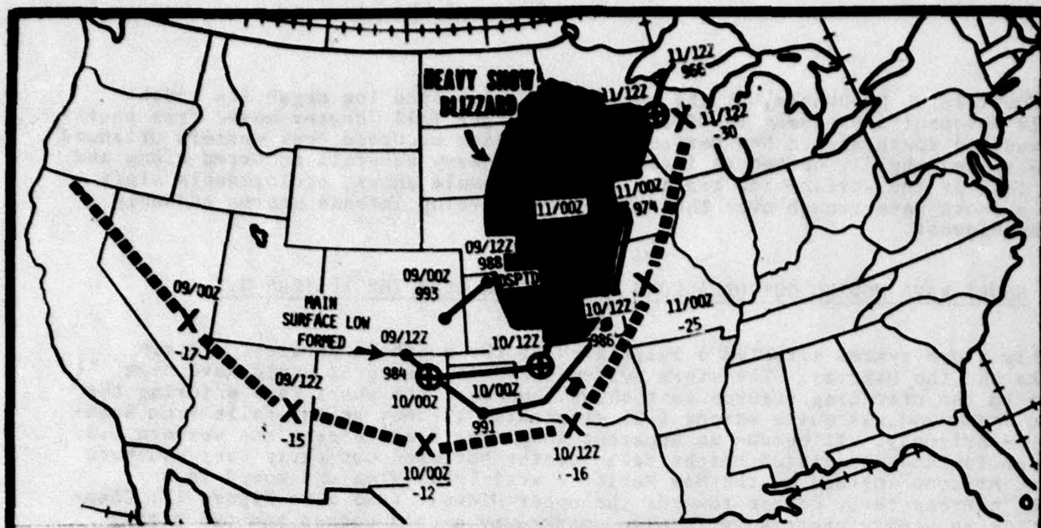


Figure 51: Composite, 8-11 Jan 1975

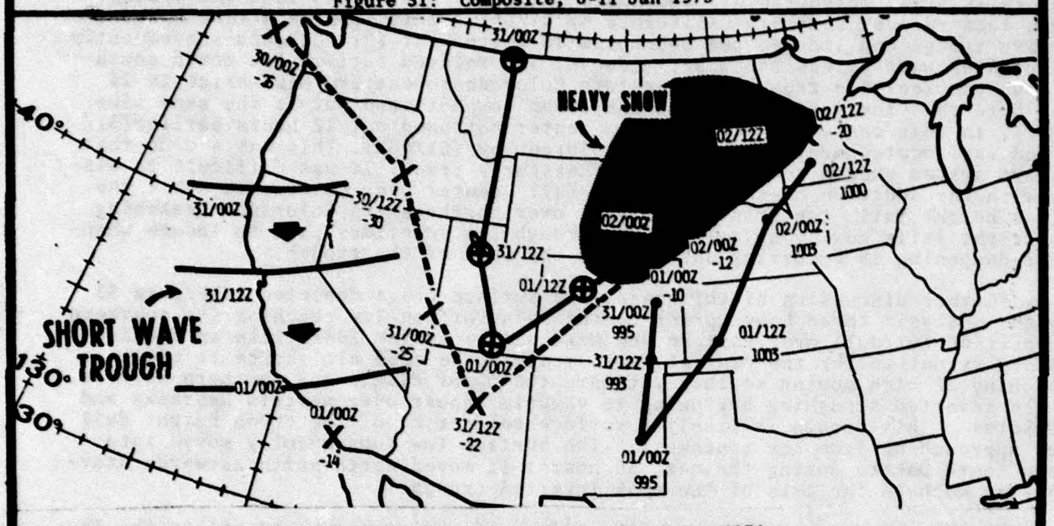


Figure 52: Composite, 30 Dec 1975-2 Jan 1976

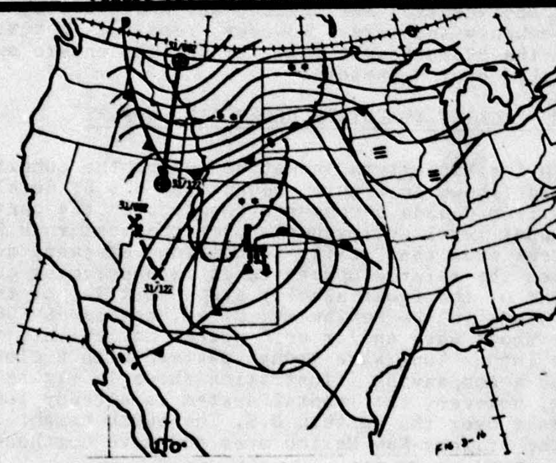


Figure 53: Surface, 21Z 31 Dec 1975

The trough entered the West Coast 36 hours earlier as a short wave trough system. From the time of the depicted 500mb analysis, intensification began, and a low became fully organized over southern Nevada during the next 12 hours. In Figure 54a, note the 500mb height falls track (for the past 12 hours) and wide contour gradient over lower California and Nevada. During this deepening period, the related mP frontal system shown in Figure 54b slowed its forward movement and eventually became stationary; the mP front developed cP characteristics due to cold air flowing in from Canada. The surface front will normally remain stationary under these circumstances until the main upper trough moves eastward. In these cases, the short wave low moves out and approaches the frontal system. As will be explained in the paragraph below, the low/associated inverted trough surface feature in the Rockies along the Colorado/Utah border (Figure 54b) should not be mistaken as the main surface system. The main surface low development (often rapid) will occur somewhere along the frontal system (usually under the 500mb height fall center track) near the Texas panhandle region.

SURFACE FEATURES: LINGERING LOWS/INVERTED TROUGHS

There are some general surface features that are indicators of probable low development along just such a stationary front when cyclogenesis aloft is occurring west of the Rockies. Surface lows and/or inverted troughs that develop and persist over or west of the Rockies when a mP or cP frontal system slows down over the Midwest are indicators that upper level trough deepening and cyclogenesis are occurring. Figure 54b shows surface features 24 hours prior to major low development along the frontal system over southwest Kansas. The closed low shown within the inverted trough appearing over Colorado and Utah in this figure was originally along the mP frontal system over Utah. This low remained nearly stationary while the mP front advanced into the western plains and was indicative that further deepening within the upper trough was occurring. In most cases, this "lingering" low/trough will not move eastward towards the front to trigger frontal cyclogenesis but will remain behind and eventually fill. In actuality,these lingering lows/ inverted troughs are no more than reflections of an approaching 500mb short wave which will become the triggering mechanism for frontal cyclogenesis. Snowfall occurring in the vicinity of the inverted trough/low is the result of the upper trough system and an upslope low level flow along the mountains. The approaching upper trough will induce storm development and a snowfall area from lee of the Rockies northeastward into the plains, while the lingering low/inverted trough (upslope flow) pattern will disappear as surface ridging begins to move into the area behind the upper trough.

There is another reason why inverted troughing/lows, along with cyclogenesis aloft, will be sustained behind the frontal system over the Midwest. The movement of cP air southward from the northern Rockies and Canada creates an inverted troughing pattern along its western boundary, separating fresh cP air from modified cP or mP air. The surface analysis will not always show a frontal boundary within this inverted trough due to the weakness of the discontinuity. In Figure 54b, cP ridging is evident across Wyoming to Colorado and is an indicator that cP air is pushing southward. A frontal system, although not significant, could have been placed along the inverted trough indicated by the dashed lines in Figure 54b. Regardless of the cause(s) that produce this lingering inverted trough/low feature, do not consider it as main surface development over the western plains, even if significant snowfall is currently occurring within it. The frontal development is still the main feature to consider (along with the 500mb height fall track) for the overall movement of the snowfall area that is to come to the central U.S.

CASE STUDIES

Figure sequence 55 through 61 are offered to give the reader a more thorough understanding of the "lingering" low and its subsequent dissipation through low level cold air advection. In each case study, discussion will focus upon the developments at 500mb and related events leading to surface cyclogenesis and the subsequent storm pattern.

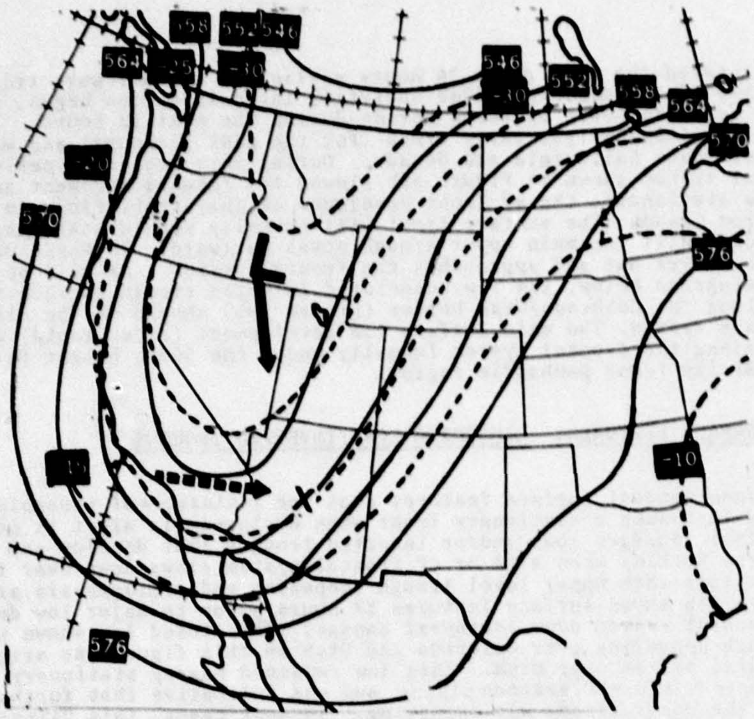


Figure 54a: 500mb, 12Z 18 Nov 1975

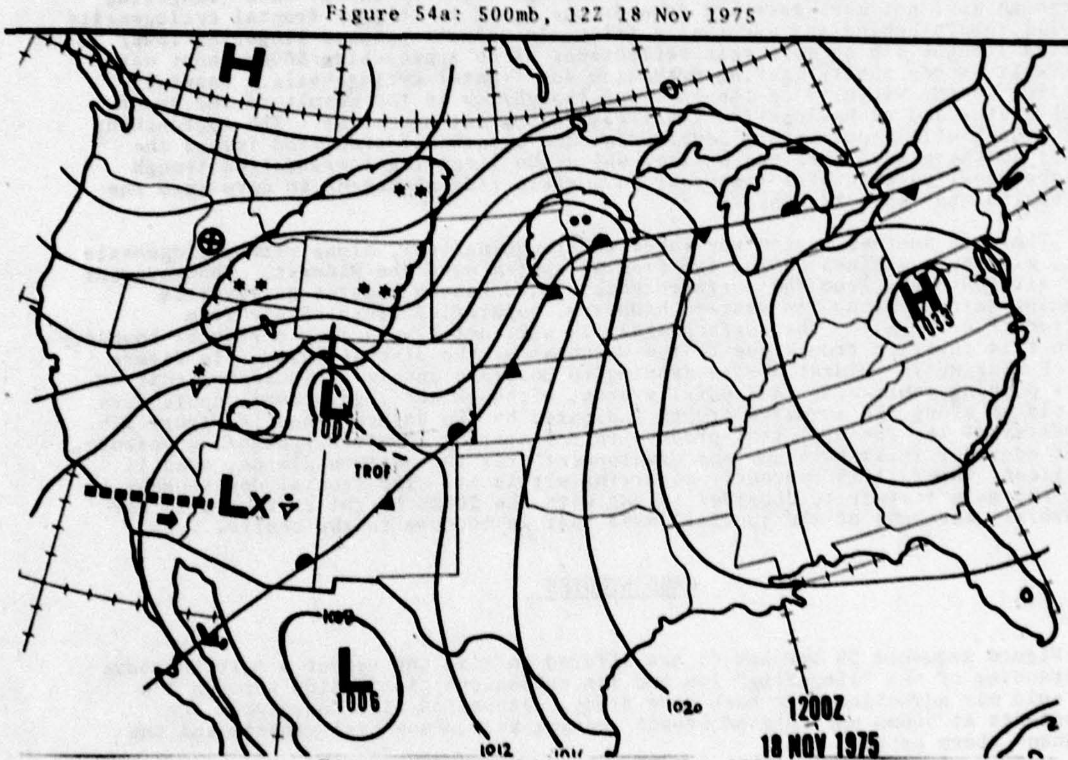


Figure 54b: Surface, 12Z 18 Nov 1975

FIGURE 54: SURFACE SYSTEMS LACKING IMMEDIATE UPPER AIR SUPPORT

EXAMPLE 1-Figure 55 shows the composite picture of the storm that was just discussed in Figure 54. The 500mb height fall center entered the lower California coast (17/12Z) and moved eastward. A low center within the trough did not appear until 24 hours later over Idaho. The 18/12Z 500mb low either moved southward or dissipated with a new low forming by 19/00Z over the Nevada-Utah area in agreement with the height fall center location and movement. The entire system bottomed out over western New Mexico and moved on a northeasterly course towards Kansas. Again, the 500mb height fall center at 19/12Z indicates that the 500mb low over New Mexico at 19/12Z should begin moving northeasterly. Meanwhile (since 18/12Z), the surface front has been stationary across the western Plains. During the twelve hours following the indication of bottoming out by the turning to a northeasterly track by the height fall center, the system became organized. At the surface (discussed below) rapid intensification occurred along the front. The eventual heavy snowfall area remained to the left of the height fall track.

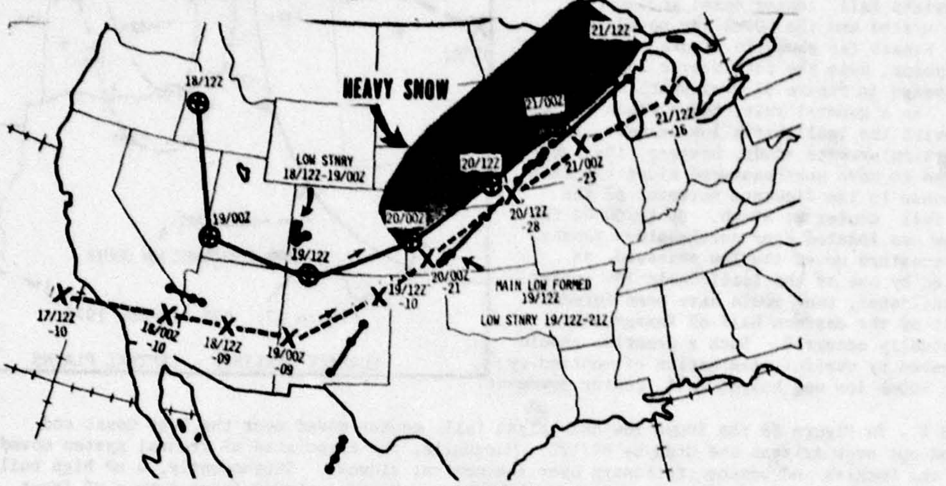


Figure 55: Composite, 18 - 21 Nov 1975

EXAMPLE 1 - SURFACE SYSTEMS LACKING IMMEDIATE UPPER SUPPORT

The resultant development of the frontal low is shown in Figures 56a and 56b. In Figure 56a no recognizable frontal low over the western plains is evident. The low shown over Utah/Colorado in Figure 54b is gone, with only the inverted trough remaining. The height fall center is approaching from western New Mexico. Light continuous snow is falling over a large area of the central Rockies within the cP air and ahead of the approaching short wave low. Three hours later (Figure 56b), a frontal low appeared over southwestern Kansas just ahead of the 500mb height fall center located over northeastern New Mexico. The Kansas low intensified rapidly and produced blizzard conditions as it moved across northwestern Kansas, central Nebraska, and the upper Mississippi Valley (see Figure 32b, Chapter 4).

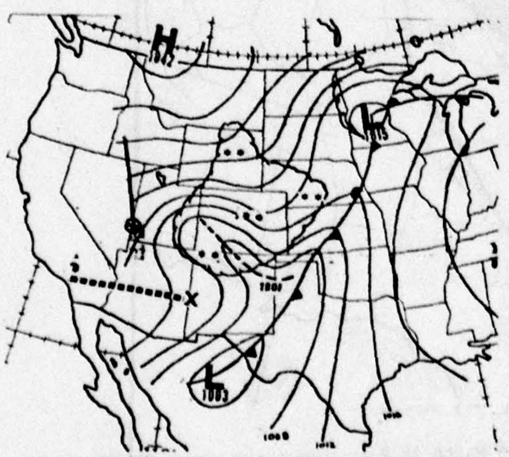


Figure 56a: Surface, 09Z, 19 Nov 1975

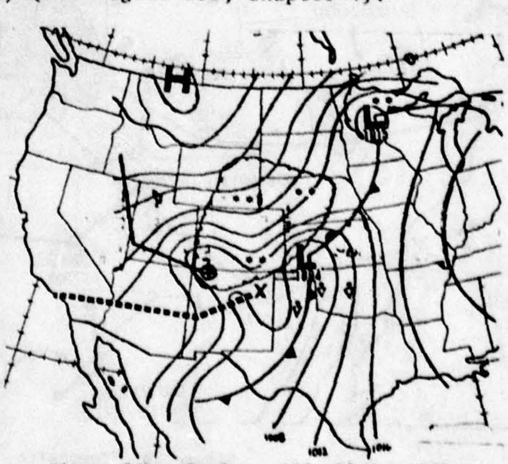


Figure 56b: Surface, 12Z, 19 Nov 1975

Figure 57 (same valid time as Figure 56b) is shown to emphasize two points. Earlier in this chapter it was mentioned that surface lows will sometimes "wait" over the western plains along an mP frontal system until the associated upper system "catches up". Storm development in this particular case is a good example of such a "waiting" surface low. In Figure 57, the frontal low developed by 19/12Z, but remained nearly stationary for at least 9 hours over southwest Kansas. The surface low began to move sometime between 19/21Z and 20/00Z as the 500mb height fall center moved across the frontal system and the 500mb low moved into western Kansas (as shown in Figure 55). As the second point, note the isallobaric low center that appears in Figure 57 over south central Kansas. As a general rule, the surface low will move toward the isallobaric low center. In this particular case study, however, the low continued to move northeastward along the front in response to the flow and movement of the height fall center at 500mb. By 20/0000Z the main low was located over northeastern Kansas. Had forecasters moved the low eastward, as suggested by use of the isallobaric low center as an indicator, snow would have been forecast for most of the eastern half of Kansas where none actually occurred. Such a practice should be tempered by careful examination of continuity of both 500mb low and height fall center movement.

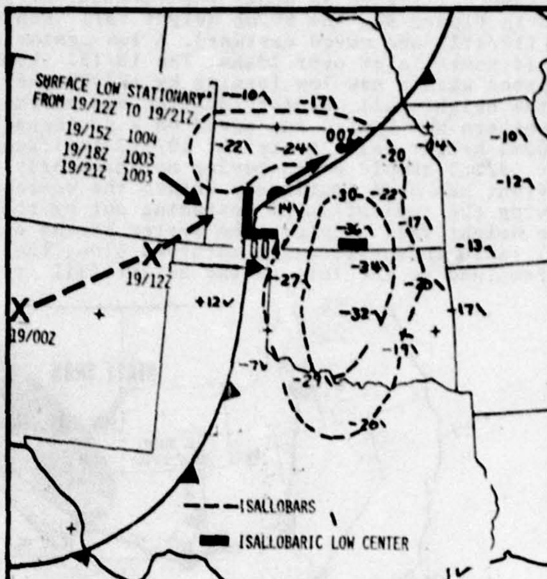


Figure 57: 12Z, 19 Nov 1975

SURFACE ANALYSIS - CENTRAL PLAINS

EXAMPLE 2 - In Figure 58 the 500mb low and height fall center moved over the West Coast and bottomed out over Arizona and Utah by 04/12Z. Meanwhile, the associated mP frontal system moved across the Rockies and became stationary over the central Midwest. Subsequently, a cP high built and slowly extended a cold ridge into the upper Midwest, changing the mP front into a cP front. The main surface low formed over northern New Mexico, moved southeastward along the front, and bottomed out over north central Texas approximately 12 hours after the upper low reached its lowest position. The surface low and upper low did not ideally stack due to the presence of the cP ridge over the upper Midwest. The significant snowfall area remained to the left of the 500mb height falls track well to the northwest of the surface low's path.

Figure 58: Composite, 3-5 March 1976

EXAMPLE 2 - SURFACE SYSTEMS LACKING IMMEDIATE UPPER SUPPORT

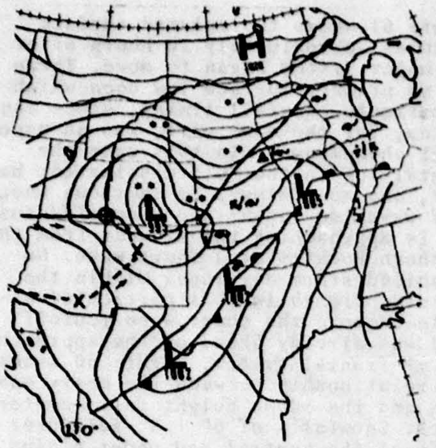


Figure 59a: Surface, 15Z, 4 Mar 1976

Figure 59b: Surface, 00Z, 5 Mar 1976

In Figure 59a, the main surface low is located over north central Texas...not Colorado. The low and inverted trough pattern over Colorado is a reflection of the upper low and should not move eastward but, instead fill. The heavy snow area, however, is occurring within the Colorado low because of the approaching 500mb low and, in addition, the low level upslope flow. The 04/12Z height fall center over New Mexico is nearing the frontal system. By nine hours later, in Figure 59b, the main surface low has organized, while the Colorado low has filled. The heavy snowfall area still remains well behind (northwest) the Illinois low. It is not recommended that the snow be forecast to progress eastward immediately behind the surface low when the upper system is a great distance away and is continuing to move northeasterly. In this case, the heavy snow moved into the eastern Dakotas and Minnesota and left eastern Nebraska, Kansas and southern Iowa without significant snowfall (i.e., the snow area remained along and to the left of the 500mb height fall center track).

EXAMPLE 3 - The third example, as shown in Figures 60 and 61, is presented to alert forecasters that heavy snow can occur with a cutoff low or a closed low within a long wave trough which has been stationary over lower California. Often, an associated surface front is lacking with these upper systems. Precipitation will increase and spread across the southern and central plains when these upper systems finally move out towards the northeast (as shown in Figure 60). The likelihood of widespread heavy snowfall is greatest in these cases when the Midwest has been dominated by a cP high pressure system over the previous 24 to 48 hours.

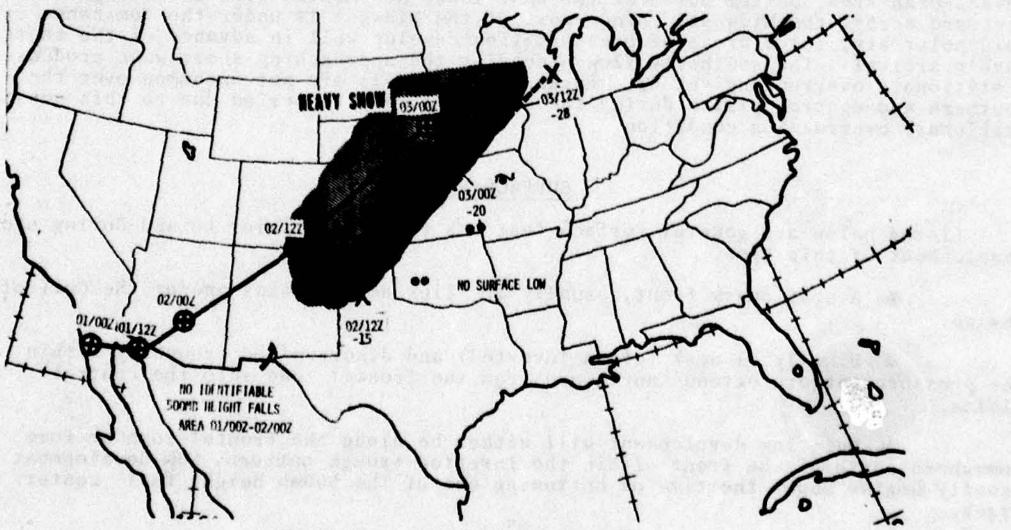


Figure 60: Composite, 1-3 Jan 1975
EXAMPLE 3 - SURFACE SYSTEMS LACKING IMMEDIATE UPPER SUPPORT

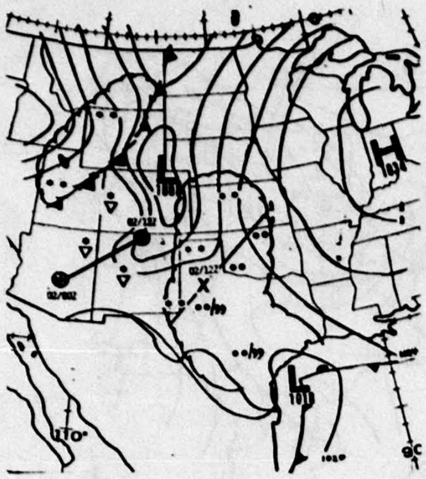


Figure 61: Surface, 09Z 2 Jan 1975

Figure 61 shows the related surface features approximately 10 hours after the upper system began to move. There was no primary surface low upon which to estimate snowfall timing, since the system, for the most part, was an upper level phenomenon. In this case the frontal low in the Gulf dissipated; however, one must always be cautious when Gulf waves do appear and a cutoff/closed low is approaching the Midwest from the southern Rockies as a short wave. No organized storm developed within the lee-side trough in this particular example because the short wave (cutoff low) was already ahead of the approaching mP frontal system. Figure 60 shows the relationship between the heavy snow area and the 500mb height fall center track. Snowfalls of 6" - 8" fell over areas of the central and upper plains.

SECTION TWO - MIDWEST UNDER THE DOMINANCE OF HIGH PRESSURE

Relationship Between mP/cP Main Low Organization and Cyclogenesis Aloft

When a large high pressure area, usually cP, prevails over much of the Great Basin, central and northern Rockies, and the Midwest area, frontal and low activity is generally confined to the southern Rockies and the southern Plains areas. Short waves moving across the southwestern U.S. (independent of long wave troughs existing east of the Rockies) continue eastward across Texas and develop frontal waves/lows over eastern Texas and within the Gulf of Mexico. Normally, this particular frontal low development continues eastward affecting the Gulf coastal states and the eastern Seaboard states. There are, however, situations where major frontal low development moves northward and affects large areas of the Midwest.

The upper air structure in these situations is a mean long wave trough oriented NE-SW from the Great Lakes to the southwestern U.S., and a strong Pacific ridge is present off the West Coast. Short waves moving from or developing over the Gulf of Alaska and/or the Pacific Northwest "drop" rapidly southward into the Arizona-Nevada-Utah area, bottom out over the west Texas-New Mexico area and swing northeastward across the Midwest. Since most of the Midwest is under the dominance of cold polar air, large areas of precipitation develop well in advance of the short wave's arrival. The southerly flow preceding the approaching short wave produces a stationary overrunning set up. Excessive snowfalls are not uncommon over the southern and central plains during the storm's formative period due to this quasi-stationary overrunning condition.

SURFACE FEATURES

Listed below are general surface features that exist prior to and during storm development of this type.

* A stationary front, usually cP, lies across Texas and/or the Gulf of Mexico.

* Usually, a weak (often inverted) and disorganized troughing within the pressure pattern extends northward from the frontal zone into the central plains.

* Main low development will either be along the frontal zone or form somewhere north of the front within the inverted trough pattern. Low development usually begins about the time of bottoming out of the 500mb height fall center track.

* Lingering lows/inverted troughs frequently appear over the southern Rockies during and after main low development over the southern plains.

CASE STUDIES

Figure sequence 62 through 65 is shown next to give the reader a more thorough picture of storm development while the Midwest was found to be under the domination of high pressure. Two examples are given.

EXAMPLE 1 - In Figure 62, the 500mb low/height fall centers, shown in 24-hour periods, moved southeastward from the Pacific Northwest towards Arizona and bottomed out over the ideal location of New Mexico and West Texas. If the Midwest had been under a receding high pressure situation, the main low development would most likely have been found within the lee-side trough over Colorado and New Mexico. However, the Midwest is under a cP high pressure system; therefore, main low development would be more likely to occur along the stationary cP frontal system in Texas. In Figure 62, the surface low associated with the short wave weakened and dissipated over New Mexico. Main low development occurred along the front in eastern Texas (21/12Z) and began to move northward when the 500mb height fall bottomed out over western Texas (21/12Z). By twenty-four hours later, the surface low had intensified and became stacked with the upper system over Missouri. Thereafter, the low turned easterly towards the Great Lakes. The heavy snowfall area remained to the left of the path of the height fall center throughout the period.

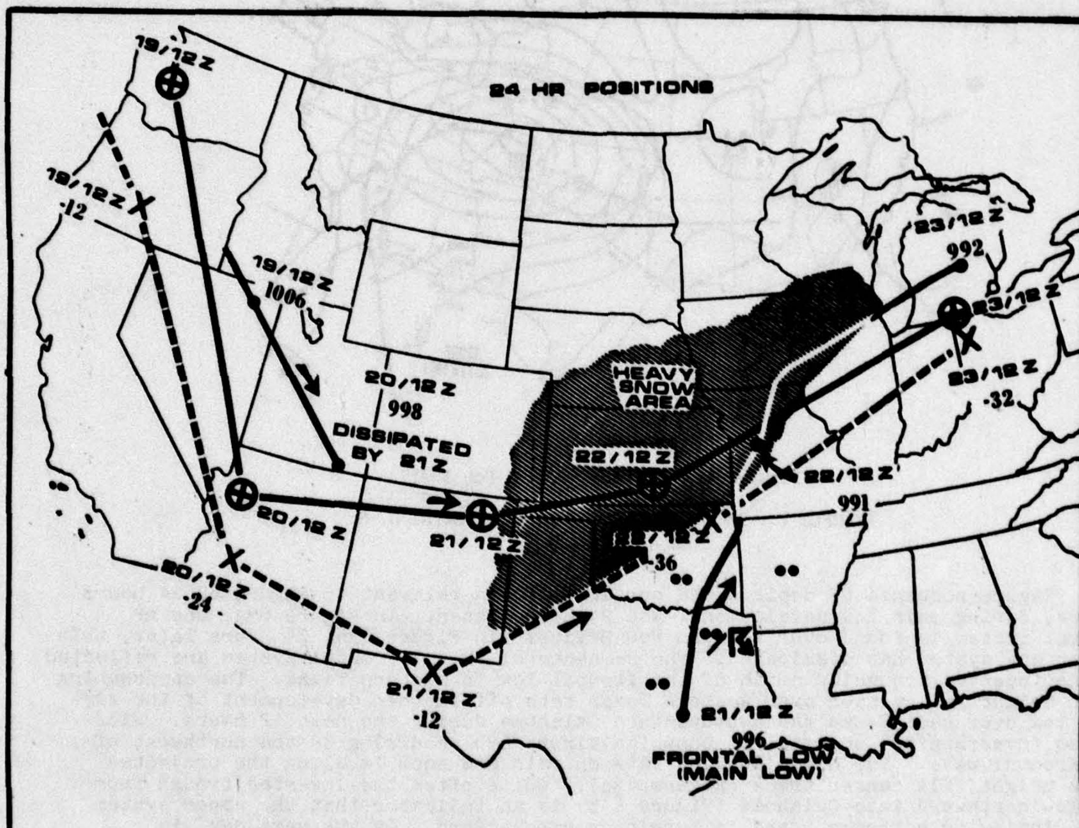


Figure 62: Composite, 19-23 Feb 1971

EXAMPLE 1 - PREVAILING HIGH OVER THE MIDWEST

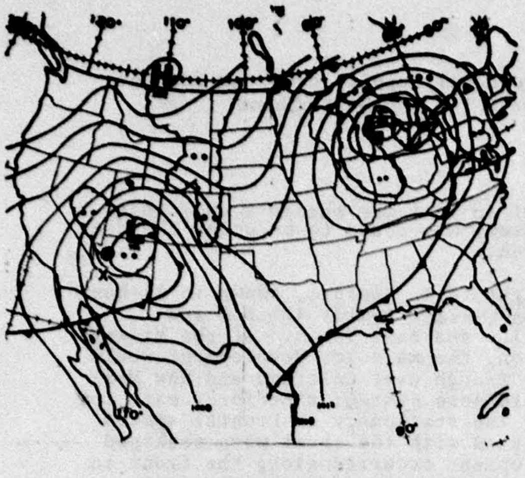


Figure 63a: Surface, 12Z 20 Feb 1971

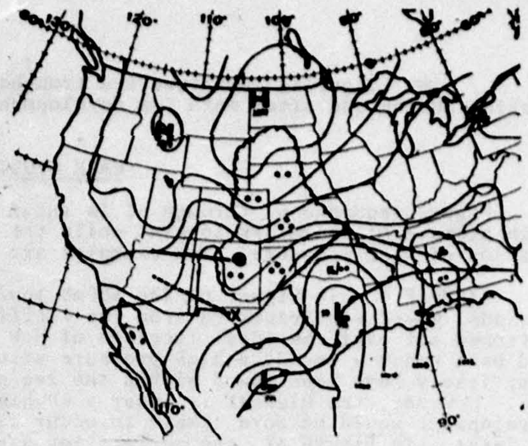


Figure 63b: Surface, 12Z 21 Feb 1971

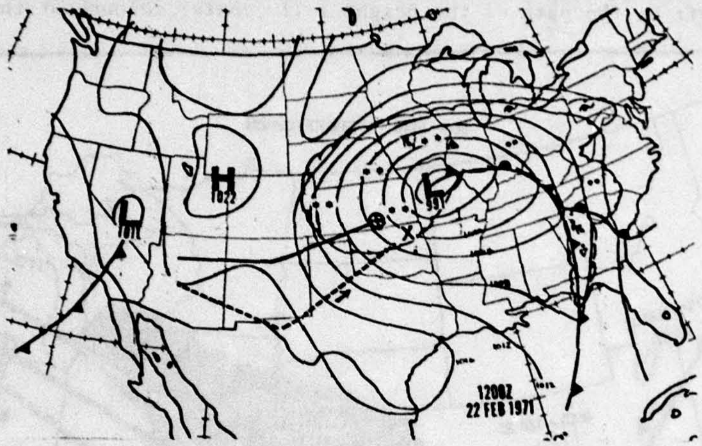


Figure 63c: Surface, 12Z 22 Feb 1971

EXAMPLE 1 - PREVAILING HIGH OVER THE MIDWEST U. S.

Figure sequence 63 depicts the surface pattern relevant to Figure 62, 24 hours before, during main low development, and 24 hours later. In Figure 63a, the mP frontal system is found over western New Mexico. In Figure 63b, 24 hours later, this mP surface system has dissipated. The remnants of the mP frontal system are reflected by the inverted troughing north of the frontal low in eastern Texas. The approaching 500mb height fall center over western Texas sets off further development of the surface low over east Texas and southeastern Oklahoma during the next 12 hours. Widespread (overrunning) snowfall is shown in Figure 63b occurring to the northwest of the frontal wave. The division line between rain and snow is along the projected 500mb height fall center track (Figure 63c). Quite often the inverted trough from the low northward into Oklahoma (Figure 63b) is an indicator that the upper system is beginning to bottom out and is turning northeastward. By the next day, in Figure 63c, the surface low has developed into a major storm centered over Missouri and is moving towards the Great Lakes. Heavy snowfall of 15-25 inches covered much of Iowa, Nebraska, Kansas, and western Oklahoma.

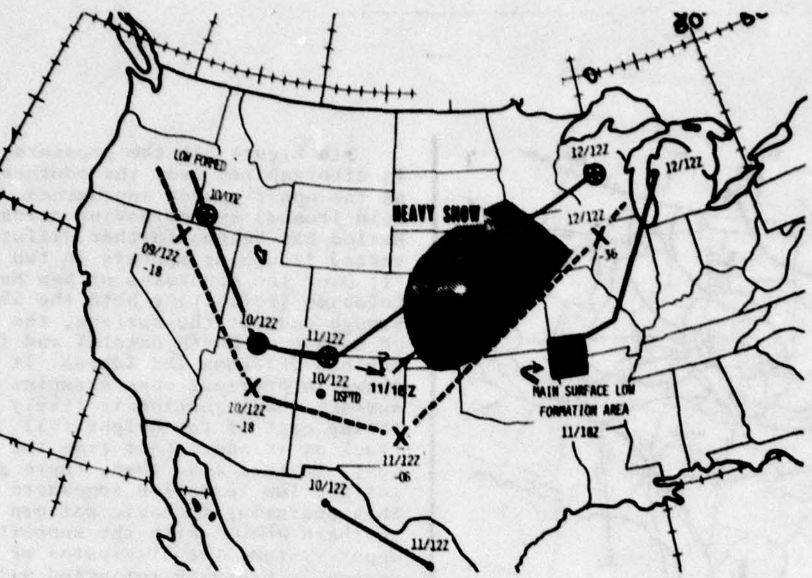


Figure 64: Composite, 9-12 Feb 1965

EXAMPLE 2 - PREVAILING HIGH OVER THE MIDWEST

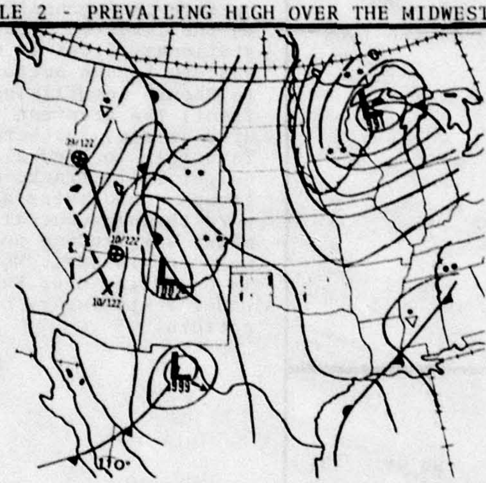


Figure 65a: Surface, 12Z 10 Feb 1965

Example 2 - This storm pattern is similar to the previous example in many respects. In Figure 64, an intensifying 500mb short wave/closed low moved from southern Idaho, where it had formed, into the southern Rockies. The original surface low (shown in west central New Mexico) dissipated, as did the low in Mexico. Development of the main surface low occurred along the Arkansas/Missouri border while the 500mb height fall center was passing from the panhandle region into southern Kansas. Note how rapidly the short wave low moved to the northeast after it bottomed out over eastern New Mexico. It is suspected that the 500mb low also bottomed out over northeastern New Mexico sometime between 11/12Z and 12/12Z, perhaps near 11/18Z (indicated by the arrows in Figure 64) in agreement with the height fall center over eastern New Mexico. Only 24-hour positions were available for this case study, so a straight northeasterly 500mb low center track is shown from northwestern New Mexico to Wisconsin rather than into northeastern New Mexico and then northeastward, as is suspected to be the actual case. The heavy snow area lies to the left of the 500mb height fall center track. Taking a closer look at this example, in Figure 65a the surface pattern 12-18 hours prior to heavy snowfalls over the central plains is shown. The storm system centered over Wisconsin had developed over the southern plains 24 hours earlier. The mP cold frontal system moving across Mexico is becoming diffused. Snow is increasing over the Rockies within the cold air and results from an upslope low level flow and the developing upper system over Utah.

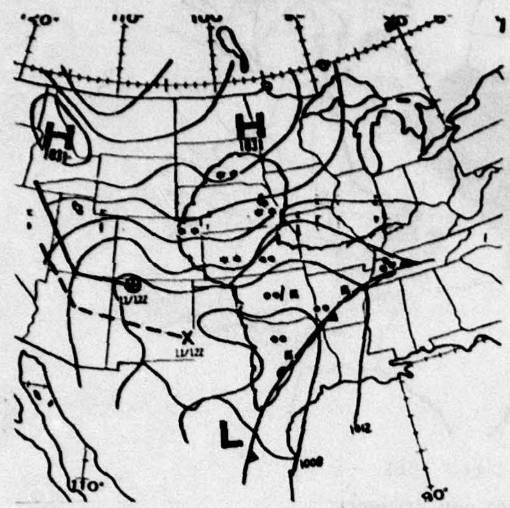


Figure 65b: Surface, 12Z 11 Feb 1965

In Figure 65b, the pressure pattern is disorganized over the southern plains as the upper system approaches. The mP cold frontal system moving across Old Mexico has become further diffused. Inverted troughing appears in two areas: (1) Over the mountains of New Mexico and Colorado (reflecting both the 500mb trough and, at the surface, the building cP high over North Dakota) and (2) over eastern Oklahoma and Kansas. It has been shown in previous case examples that main surface low formation is likely under or to the east of the height fall center track as it approaches from the southwest. In this case then, there should be surface low formation somewhere within this confusing isobaric pattern over the southern plains with the support of the upper system. The dissipated mP frontal system is probably reflected within the inverted troughing over Oklahoma and eastern Kansas. The most likely area for surface cyclogenesis is, therefore, within the inverted troughing north of the stationary front in western Missouri and eastern Kansas because that is where (although insufficient to support a cold front) the greatest thermal discontinuity exists. Furthermore, the low is favorably located along the ideal 500mb height fall track. Within the inverted trough, cold polar air is moving southward through central Kansas with warm, moist air flowing northwestward towards western Missouri. Moderate to heavy snow is occurring over Kansas and Nebraska under a stationary overrunning upslope pattern.

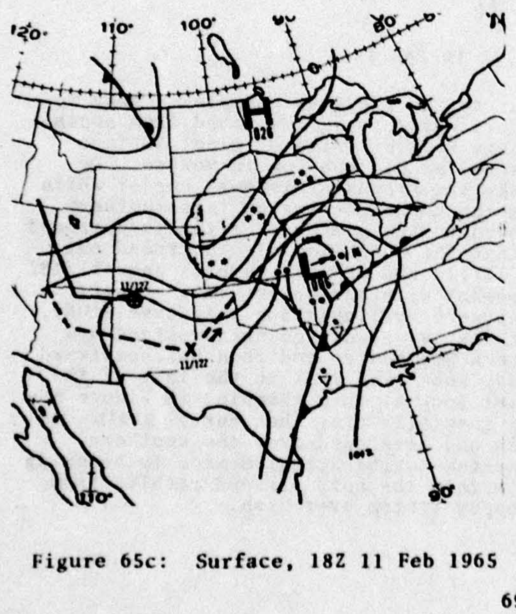


Figure 65c: Surface, 18Z 11 Feb 1965

By six hours later, a surface low has developed in southwestern Missouri north of the stationary front, as shown in Figure 65c. This low developed rapidly and moved to southern Michigan 18 hours later (shown in Figure 64). Heavy snowfall continues over the central plains. Offutt AFB, Nebraska, received 19"; Omaha received 23"; and surrounding areas had up to 30". The rain/snow line is oriented SW-NE across eastern Kansas to extreme southeastern Iowa; the snow area is some distance northwest of the track of the main surface low in good alignment with the height fall center path.

SECTION III: SPECIAL CASES

CYCLOGENESIS ALOFT APPROACHING FROM THE NORTHWEST

Low pressure systems developing along the quasi-stationary front over and east of the Rocky Mountains can also produce significant snowfalls over the Midwest. Discussion of the associated upper level and surface features was presented in Chapter 4. In review, a prevailing cP air mass exists over a large portion of the Midwest. Developing short waves move further inland across western Canada and the northern Rockies because the Pacific ridge extends further inland over the western U.S. These short waves continue southeasterly and bottom out within the long wave trough over the central Midwest. Considerable snowfall often develops within the cold polar air as the short wave approaches. The related surface low is usually located some distance from the upper system.

CASE STUDIES

Example 1. Figure 66 shows the relationship between movement of the 500mb low, 500mb height fall center, and the surface low. The main surface low developed over southern Alberta and moved southward along the Rocky Mountains to west Texas where it bottomed out. The reason why the Alberta low continued southward rather than eastward is obvious: the continuous digging of the height fall center toward the southern Rockies. Note the moderate height fall from Montana to Texas as the system moves down the Rockies. The height fall center bottomed out within the long wave trough over Oklahoma, with the values increased again (-16 over Missouri) as a northeasterly track is taken. Note that the height fall center has shifted eastward between 26/00Z and 26/1200Z although the 500mb low center was still moving southeastward. The 500mb low center, however, did shift eastward by 27/00Z as it bottomed out. The main surface low moved down the frontal zone along the east slope of the Rockies to west Texas due to the presence of a cP ridge over the Plains, Figure 67a. The low reached bottom at the same time the height falls bottomed out (26/00Z). The storm became a mature storm between 26/12Z and 27/00Z as it moved northeast. The low was a weak frontal disturbance (while bottoming out although central pressure didn't change much) while moving easterly across Texas. Figure 67b shows the surface pattern at 26/1200Z during the storm's history. The surface low is in the process of turning northeastward, indicated by the strong inverted trough. The 500mb trough is reflected at the surface by this inverted trough. Widespread snowfall developed north of the 500mb height fall center track as Gulf air overran the cold air mass during the period when the entire system was reaching its lowest position within the long wave trough. During the following 36 hours, the three centers converge as they move northeastward. Heavy snowfall resulted along and to the north of the height fall center track from the central plains northeastward to the Great Lakes.

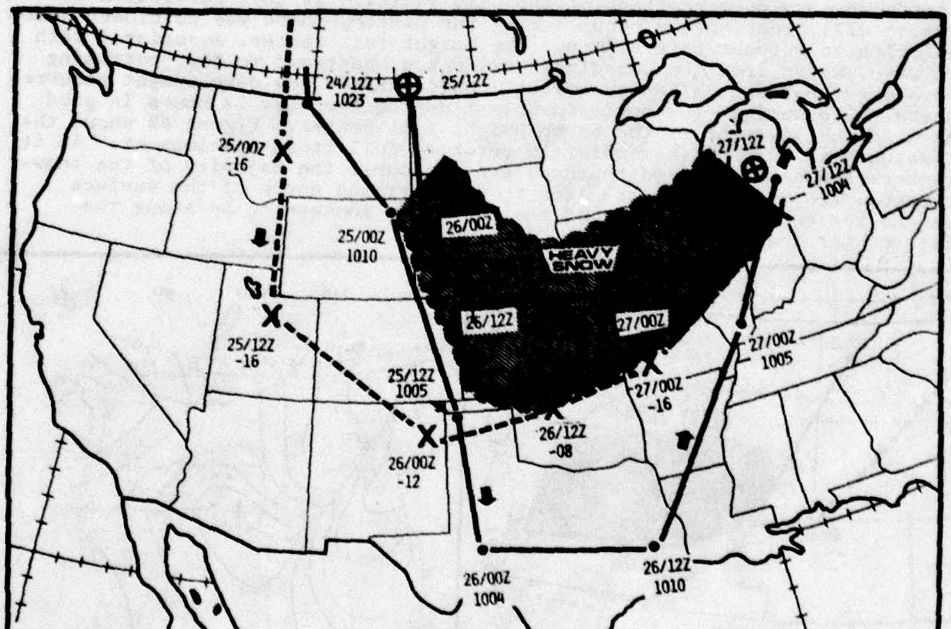


Figure 66: Composite 24-27 Nov 1975
EXAMPLE 1
STORM SYSTEMS APPROACHING FROM THE NORTHWEST

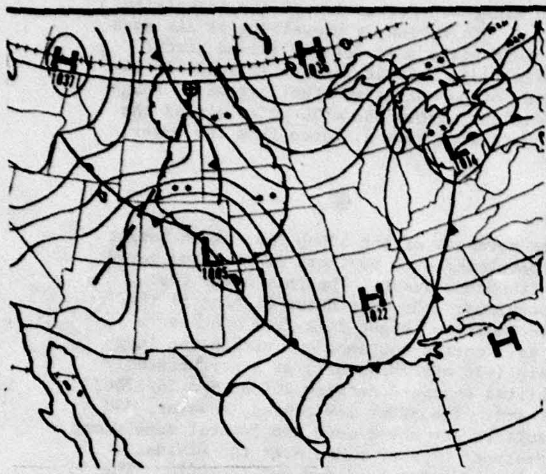


Figure 67a: Surface, 12Z 25 Nov 1975

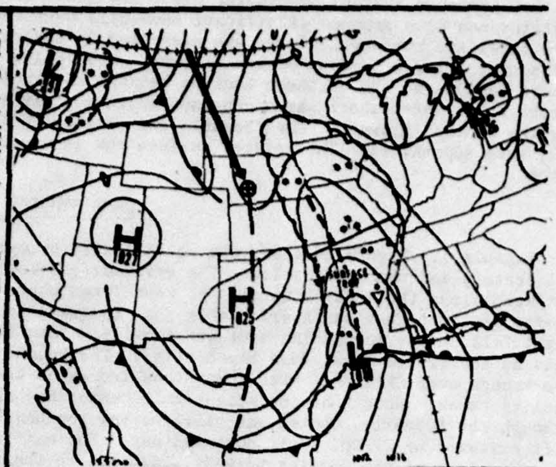


Figure 67b: Surface, 12Z 26 Nov 1975

Example 2. This example is presented to show storm development and the occurrence of heavy snow without the support of a closed upper low. Figure 68 depicts the related movements of the 500mb height fall center and the surface low. This particular storm system produced initially unforecast heavy snow over most of Nebraska and Iowa and the extreme northern parts of Kansas and Missouri as shown. It also produced snow over portions of the Ohio Valley. In this particular instance, which will occasionally occur during the winter, there was no closed 500mb low circulation to support this system. The height fall center, associated with the short wave, moved from the Canadian Rockies southeastward to the "bottoming out" area along the Nebraska/Kansas border. Main surface low development occurred over Montana. The surface low moves southeast during the next 12 hours in good agreement with the movement of the 500mb height fall center. Figure 69 shows the surface features at 19/0000Z, immediately prior to full storm development. As it moved from eastern Kansas toward southeastern Missouri, the majority of the snowfall occurred. The heavy snow area lies to the east and north of the surface low track and the southern boundary of the snow area is seen to be along the height fall center track.

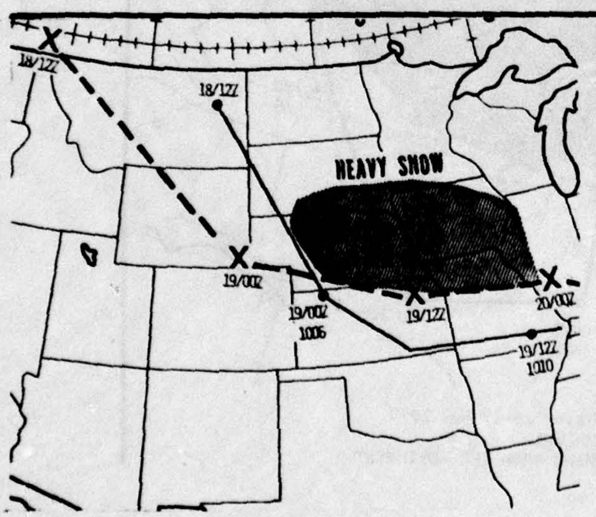


Figure 68: Composite, 18-20 Jan 1975

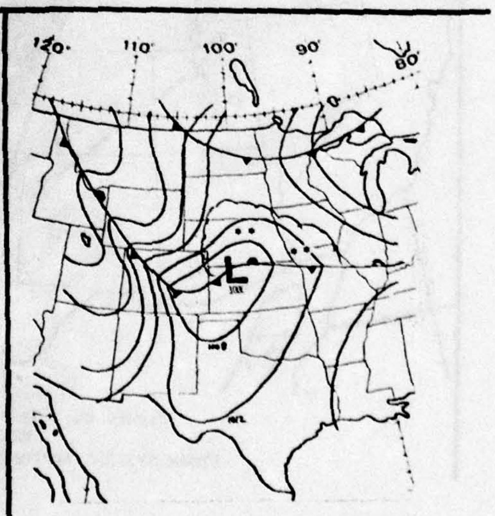


Figure 69: Surface, 00Z 19 Jan 1975

EXAMPLE 2: STORM SYSTEMS APPROACHING FROM THE NORTHWEST

PRECIPITATION DEVELOPMENT

Rapid development of clouds and precipitation areas over the Great Plains have frequently surprised forecasters. The absence of significant precipitation over areas of the southern and central Plains during the developmental period of a storm system over the Rockies is quite common, especially with a receding high pressure pattern. Precipitation often develops rapidly while the system bottoms out and there is subsequent stacking over the southern Plains. It is usually a few hours prior to the bottoming out period of the 500mb low that moisture in the lower levels (Gulf or residual stratus) begins advecting northward from Texas into the developing system. Moisture is transported into the middle levels by an increasing uplift of air along and east of the trough axis. In this regard, the concluding section of this chapter will discuss two developing precipitation patterns. The two patterns will be identified as being associated with either a receding high pressure pattern or a prevailing high pressure pattern, as has been done throughout this Technical Note.

SURFACE HIGH RECEDING FROM THE MIDWEST

The southern and central Plains are usually under a warm southerly flow on the back side of the high just prior to storm development. The presence of a low level jet and subsequent northward advection of Gulf stratus occurs frequently. Gulf moisture continues northward and is lifted into the middle and upper levels and eventually circulates into the upper low which, by this time, has begun moving out of the Rockies. Snow develops within the colder air and the precipitation area increases as the system continues to intensify. Figures 70a through 70e depict a storm's passage over the Midwest. Surface features and 500mb low center and height fall center (tracks) have been added to those charts closest to the 00Z and 12Z 500mb data to show the relationship between the bottoming out period and increased precipitation. In Figure 70a, no precipitation is observed over the plains. Scattered showers have developed along the cold front near El Paso, Texas (ELP). Scattered areas of precipitation are likely within the cold air associated with the approaching system west of the Rockies; however, significant precipitation develops later over the plains. Figures 70b and 70c show the gradually increasing precipitation areas over eastern Texas, then the southern Plains, as Gulf moisture flows northward. In Figures 70d and 70e, the increasing precipitation area has spread into the central Plains and Ohio Valley as the upper low (500mb) has moved to northwestern Oklahoma (24/12Z). Moderate snow is falling over the northern Texas panhandle, eastern Colorado and western Kansas area.

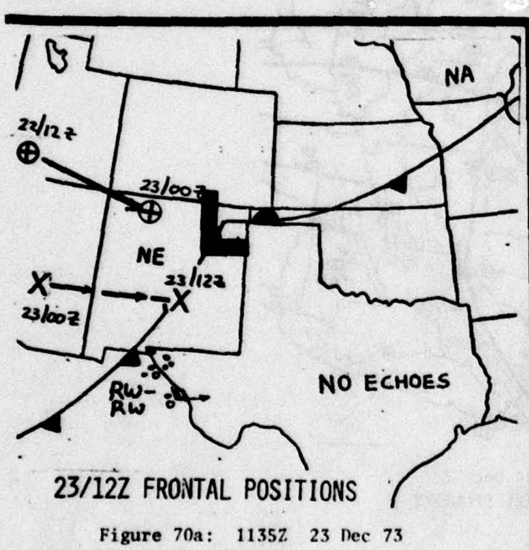


Figure 70a: 1135Z 23 Dec 73

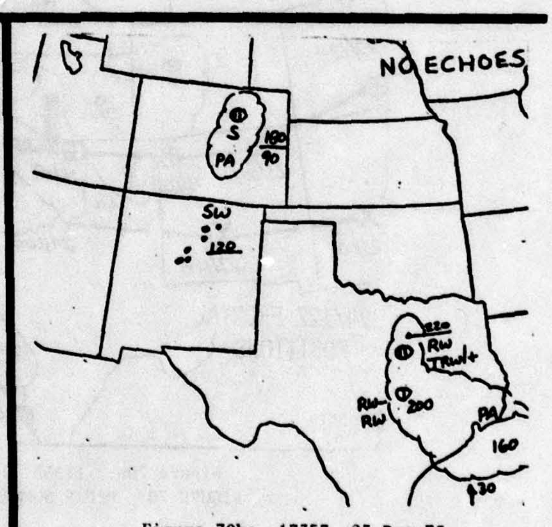


Figure 70b: 1735Z 23 Dec 73

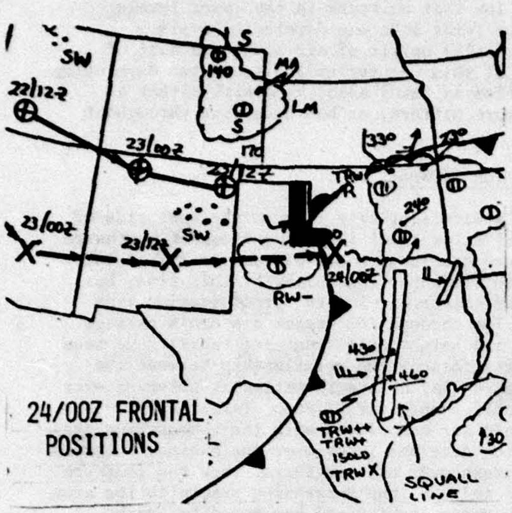


Figure 70c: 2335Z 23 Dec 73

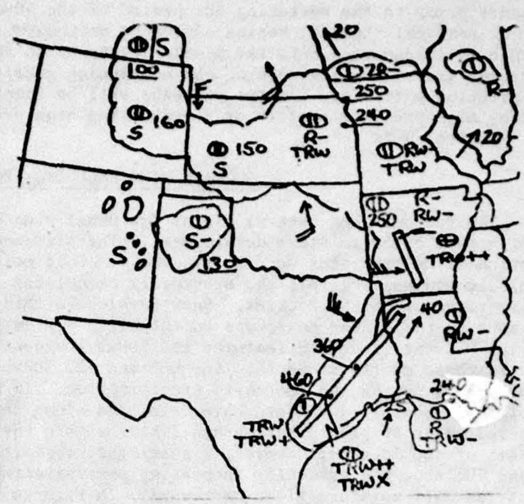


Figure 70d: 0535Z 24 Dec 73

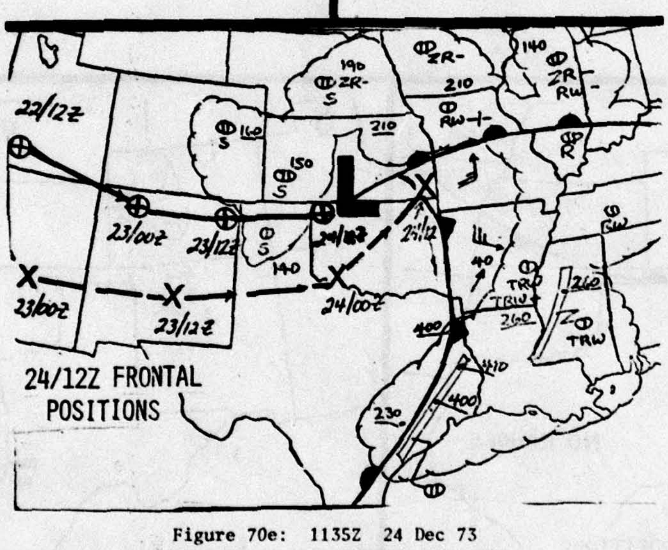


Figure 70e: 1135Z 24 Dec 73

FIGURE 70: RADAR SUMMARY SEQUENCE

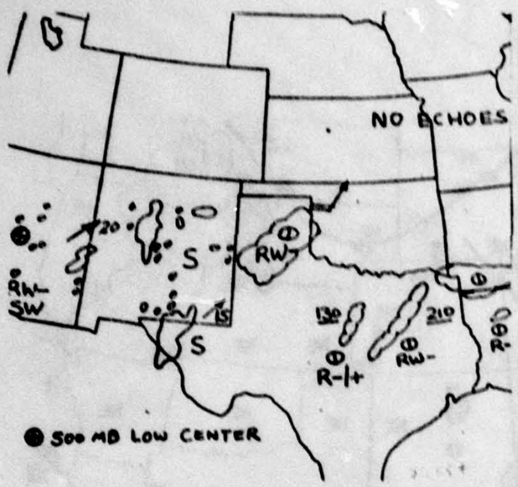


Figure 71a: 2335Z 1 Jan 75

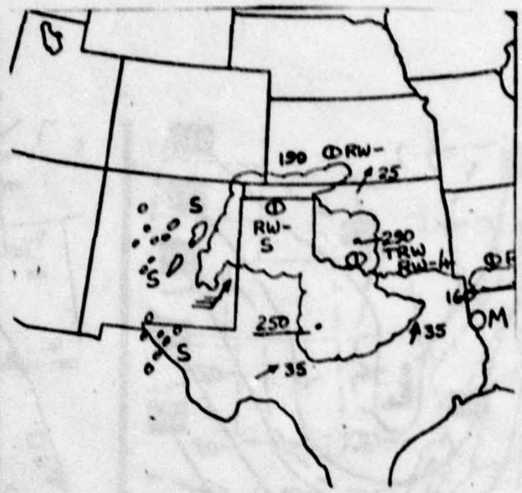


Figure 71b: 0235Z 2 Jan 75

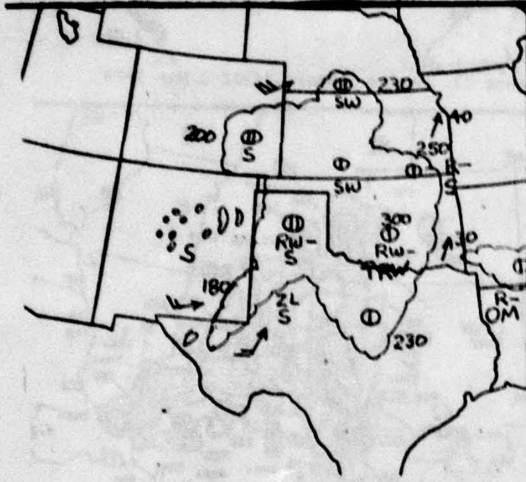


Figure 71c: 0535Z 2 Jan 75

Figure sequence 71a through 71e, shown in three-hour increments, is presented to show another example of this rapid development and movement of precipitation. In this case there is no readily identifiable surface low to track. A closed low within the 500mb long wave trough over the southwest U.S. moves rapidly northeastward toward the central states and the surface high recedes from the northern Plains into the Ohio Valley. In Figures 71a and 71e the 500 low center location has been added (as in the previous example) to show the 12-hour movement of the upper system. Note the rapid development of the precipitation area. In this particular example the 500mb low and precipitation area were moving northeastward at 40 knots. Further history of this storm was shown in Figures 60 and 61 and is discussed earlier in this chapter.

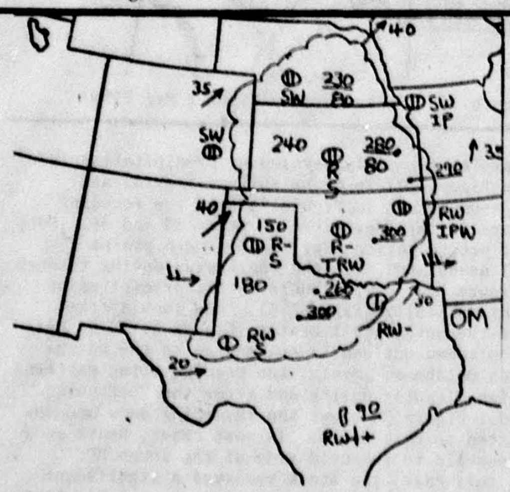


Figure 71d: 0835Z 2 Jan 75

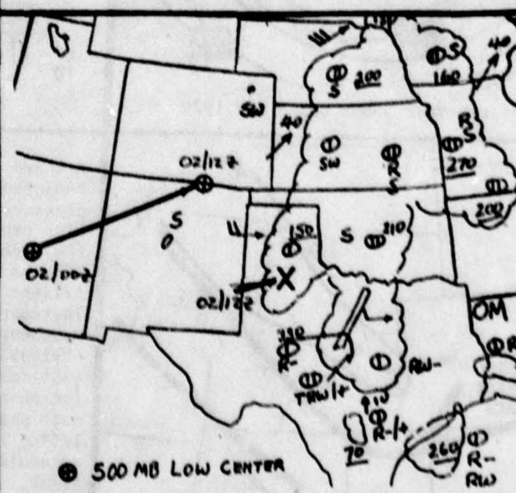


Figure 71e: 1135Z 2 Jan 75

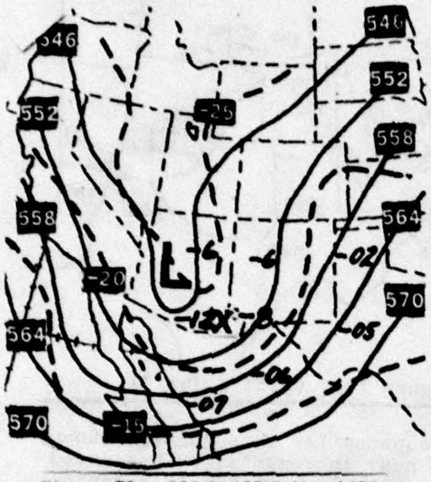


Figure 72: 500mb 12Z 2 Mar 1979

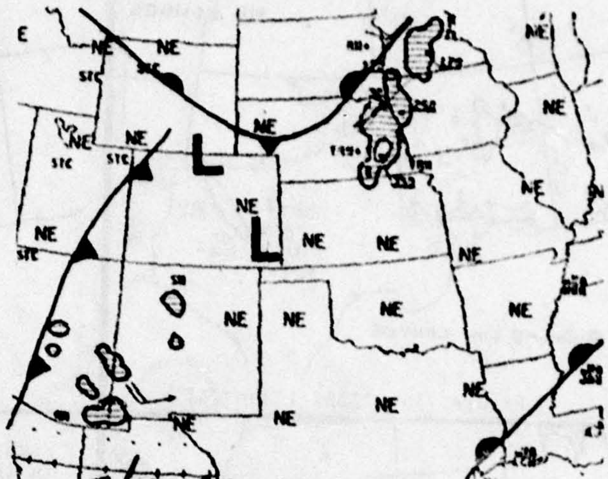


Figure 73: Radar Summary 1135Z 2 Mar 1979

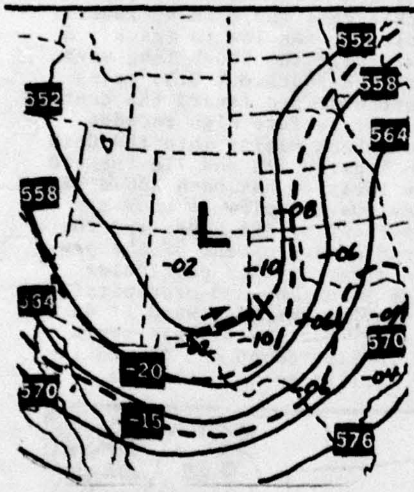


Figure 74: 500mb 00Z 3 Mar 1979

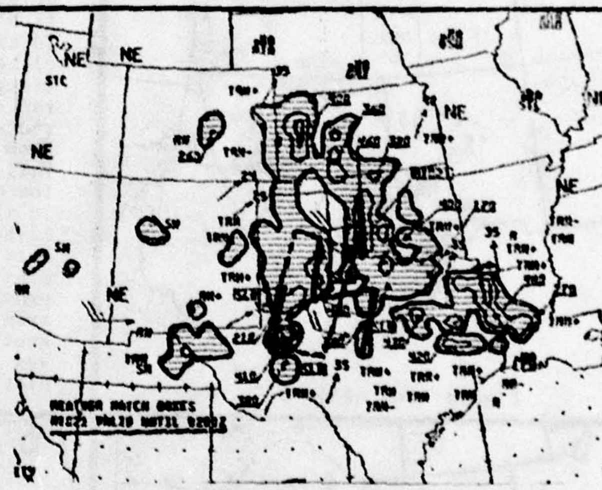


Figure 75: Radar Summary 1935Z 2 Mar 1979

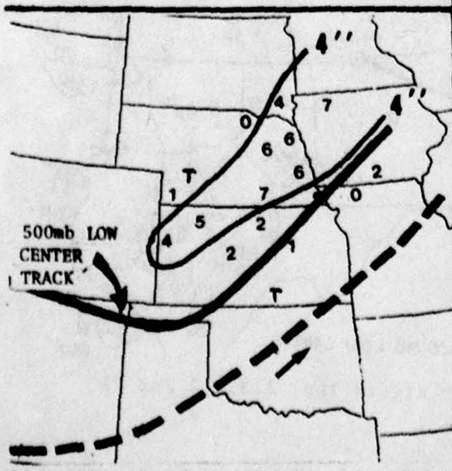


Figure 76: Snowfall 12Z 3 Mar-5 Mar 1979

A third example of rapidly developing precipitation is depicted in Figures 72-76. The surface frontal and pressure systems shown in Figure 73 fits the receding high pressure pattern described on pages 35 and 36. Note the lack of precipitation over the southern plains (Figure 73) associated with the short wave moving through Arizona (Figure 72). Eight hours later, precipitation increased dramatically (Figure 75). Now look at the movement of the height fall center (Figure 74). It has obviously bottomed out and is now moving to the northeast towards Oklahoma. Again, the precipitation patterns increase significantly during and after the "bottoming out" period. Figure 76 shows the resulting snow accumulation related to this storm. In most cases, heavy snow accumulations lie to the cold side of the 500mb HFC track. In this case, the storm received a significant amount of warm advection. As described on page 51, heavy snow accumulation will fall to the left of the 500mb low center track if the storm becomes sufficiently warm.

SURFACE HIGH PREVAILING OVER MIDWEST

When the central U.S. has been under domination by strong high pressure for 24 to 48 hours, a stationary frontal boundary is normally found over Texas eastward across the Gulf of Mexico with cold polar air prevailing over most of the Midwest (Figures 77a and 77b). A long wave trough usually lies west of the Rockies. At the start of development a generally combined area of precipitation develops along and to the north of the frontal boundary. Gradually, moisture spreads northwestward across Texas into New Mexico from the Gulf. This pattern remains fairly stagnant until a short wave system moves out of the long wave over Arizona and New Mexico (Figures 78a and 78b). Once the short wave begins to turn northeastward the precipitation area begins to expand quite rapidly (overrunning). Extensive areas of precipitation spread northeastward across the Midwest as the associated short wave moves northeastward from the southern Rockies. Figure sequence 79 depicts such a precipitation pattern under a prevailing high pressure system. This system produced a foot of snow in Kansas and Missouri and gave Texas everything from an ice storm in the Dallas area to 1½ inches of rain at College Station.

In the precipitation type shown, the intent has been to impress upon forecasters the importance of constantly watching for any sign that will give warning of an impending storm formation. In the case of a receding high pattern precipitation develops rapidly over the southern plains usually in the Texas panhandle - western Oklahoma area. Precipitation development associated with a prevailing high pattern increases gradually over a large area of the southern plains and generally provides ample warning that increased overrunning ahead of the approaching upper trough is occurring. No matter whether all the signs are there (at the 500mb, at the surface, or on the progs) or not, closely watching the upstream changes as they are occurring remains one of, if not the most important responsibilities of the forecaster.

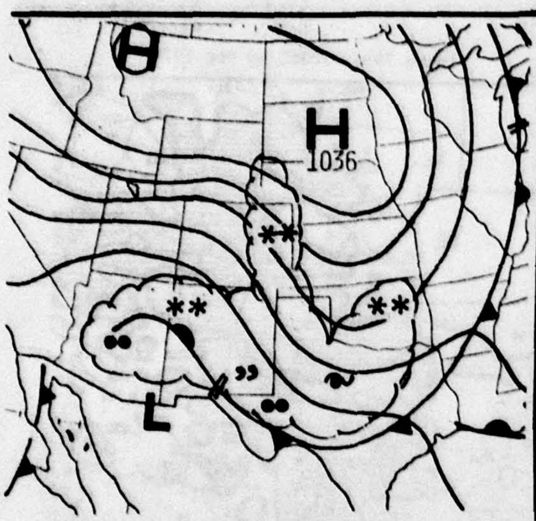


Figure 77a: Surface, 12Z 30 Dec 1978

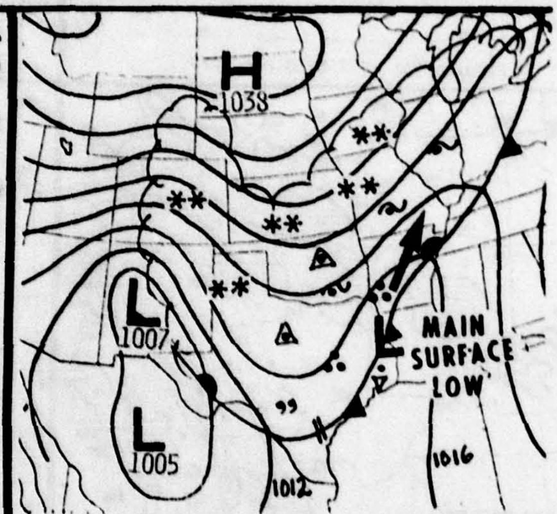


Figure 77b: Surface 12Z 31 Dec 1978

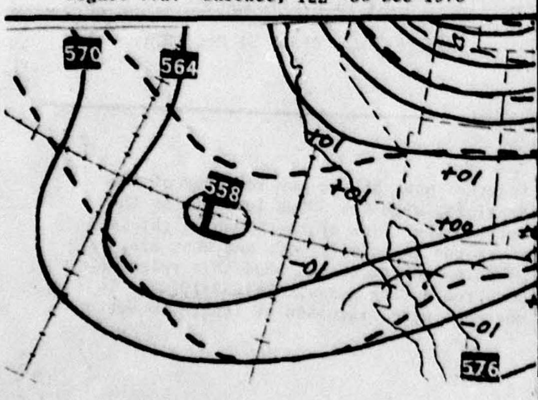


Figure 78a: 500mb, 00Z 30 Dec 1978

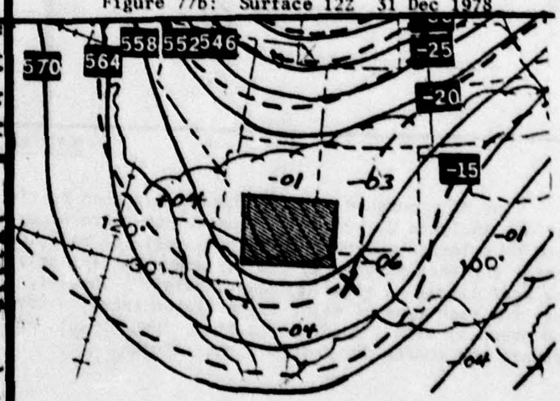


Figure 78b: 500mb 12Z 31 Dec 1978

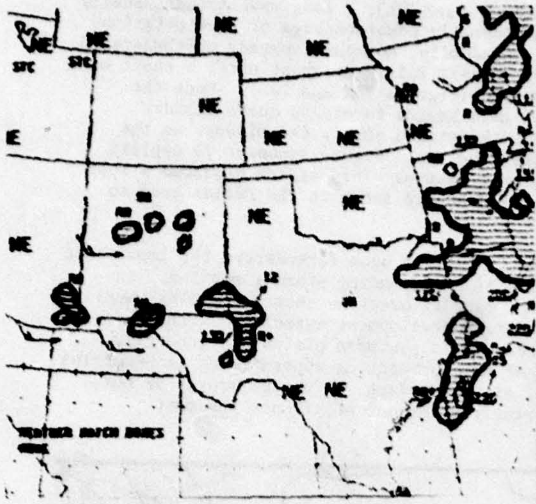


Figure 79a: 0735Z 30 Dec 1978

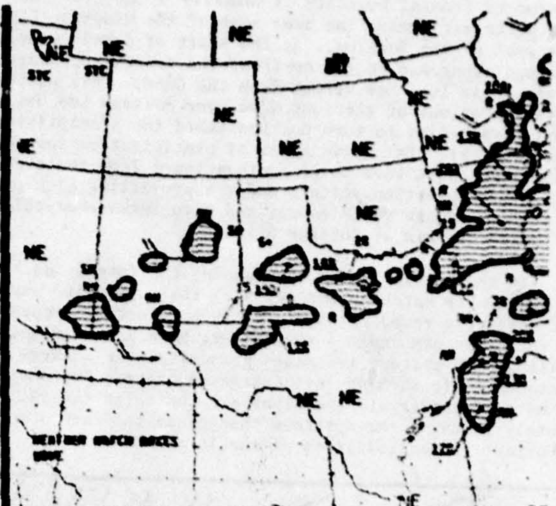


Figure 79b: 1035Z 30 Dec 1978

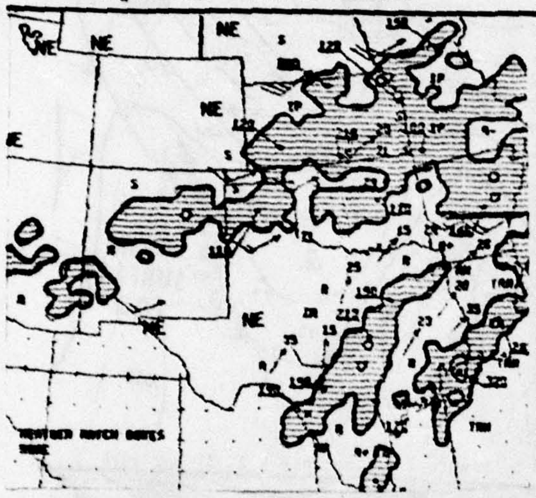


Figure 79c: 1935Z 30 Dec 1978

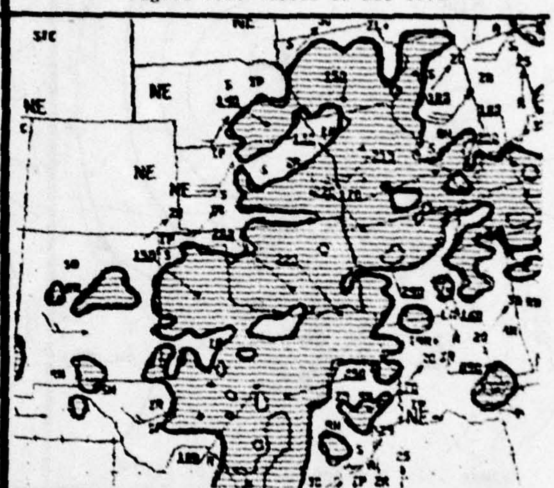


Figure 79d: 0835Z 31 Dec 1978

SUMMARY

The main purpose of this chapter has been to tie together many of the key features of the surface analysis with the developments that are occurring aloft, with the 500mb level being the area of primary concern. There is a definite relation between the track of the 500mb height fall center and what happens on the surface...particularly, where the storm will move and what area is the most likely to receive heavy snowfall. The intent of this chapter was to show this relationship for each type of major storm system known to have occurred during research (1952-1976). In the process, main low identification, development, and movement were discussed at length to better prepare the reader for future winter storms.

CHAPTER 6

SUMMARY

INTRODUCTION

This chapter is offered as a summary of what has been presented so far throughout this technical note and some information from the companion note, 3WW Tech Note 76-1, Low Level Moisture Advection. First, condensed summaries on the recognition of synoptic features and the use of subjective rules (both at and above the surface) discussed throughout the tech note for short and long wave systems are shown. Selected illustrations for each summary are included and figure references are noted where applicable. The number(s) enclosed in parentheses are page numbers within the tech note and serve as a reference.

The second portion of the summary show relationships between the tracks of the 500mb low center, the 500mb height fall center and the main surface low and the likely areas of heavy snowfall for some areas of the Midwest. While most of the study refers to the Great Plains area, it should be noted that the same relationships appear valid throughout the entire Midwest area from the Rockies on the West to the Appalachians on the East.

Finally, a case study is presented of an intense storm system (blizzard) that developed over the central plains during the period January 8-11, 1975.

Note: In the following figure sequences, the surface analyses shown are exact duplicates of the NWS facsimile charts. No reanalyses or repositioning of frontal boundaries was attempted prior to use in this Technical Note.

SUMMARY
RECOGNITION OF TIME-PHASED SYNOPTIC FEATURES FAVORING HEAVY SNOWFALL OVER THE GREAT PLAINS
SHORT WAVE SYSTEMS

	WEST OF ROCKY MOUNTAINS					OVER/EAST OF ROCKY MOUNTAINS			
	UPPER FLOW PATTERN AT ONSET OF DEVELOPMENT	JET STREAM (300MB)	500MB HFC* MOVEMENT/ TENDENCY	500MB CYCLOGENESIS AREA	WARNING	JET STREAM (300MB)	500MB HFC* MOVEMENT/ TENDENCY	500MB LOW	WARNING
500MB CYCLOGENSIS DEVELOPS WEST OF ROCKIES (EARLY WARNING)	N-S short wave moving towards/ over West Coast Fig 83. (5)	NW-SE jet digs into trough's base usually over lower CA. Jet max behind trough. Fig 82 (2)	HFC appears ahead/along trough's axis. HFC decreases >-15 per 12 hrs. HFC moves SEwd and incrs in value. Fig 83 (8,9)	Forms above HFC within wide contour/ thermal gradient. Cold pocket present. Low appears ESE of hatched area shown in Fig 83. (5,6).	HFC movmt to the SW or S instead of SE indicates contd trof deepening and deceleration; system becoming major trough. Upper low becomes stnry or continues southward. See page 83 (10) Decrease in HFC values during SEwd movmt may indicate filling.	Incrg amplitude ovr srn Rockies/Plains. Jet SW-NE east of Mississippi River. Wind max within trof's base during storm dvlpmt over Rockies. Jet max lies along SW-NE jet segment when storm is over Great Plains. (2) See WARNING ↓	Anticipate recurvature when HFC values decrease or remain the same from previous 12 hr HFC value. Ideal recurvature area: northern TX and OK. (6,7,8)	Low recurvature should occur within subsequent 12 hrs of HFC recurvature (7). Most intense storms are negative-tilt trofs movg NEwd across srn Rockies/Plains.	500mb low may not develop within fast-moving short waves. (>35 kts/hr). Also, in fast-moving short waves, HFC values may not decrease prior to and during recurvature (7).
500MB CYCLOGENESIS DEVELOPS OVER ROCKIES (LATE WARNING)	Generally zonal or weak troughing over West Coast. Vorticity max, cold advection etc within flow increases deepening. Fig 85.	W-E jet across central/northern U.S. within zonal flow. Jet max approaches West Coast. Jet max drops southward with increasing amplitude. Fig 84, 86 .	HFC appears over West Coast within zonal flow. HFC moves SEwd as jet drops Swd. Look for HFC values of >-15 per 12 hrs. (15,16, 17) Fig 87.	Contour/thermal gradient continues to widen above HFC. (15,16,17)	Same as above.	Same as above. WARNING: See "Wind Maxima Appearing Southwest of an Upper Low" pages 3 and 4.	Same as above.	Low develops within wide contour/thermal gradient over southern Rockies/Plains. (15,16)	[illegible] as above. Note: These storms develop rapidly and become vigorous over the Midwest.

See pages 81 and 82 for surface and low level features. * HFC - 500mb height fall center.

Figure 80: Receding High

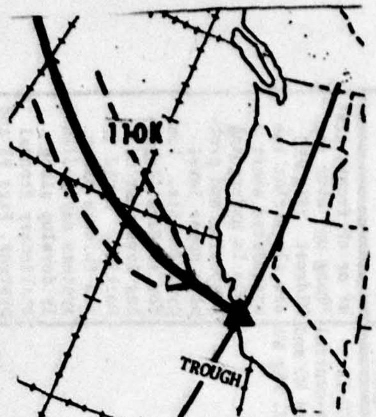


Figure 82: 300mb 12Z 1 Mar 1979

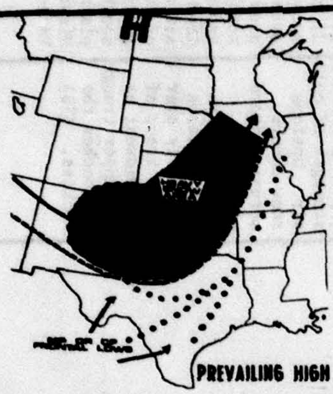


Figure 81: Prevailing High

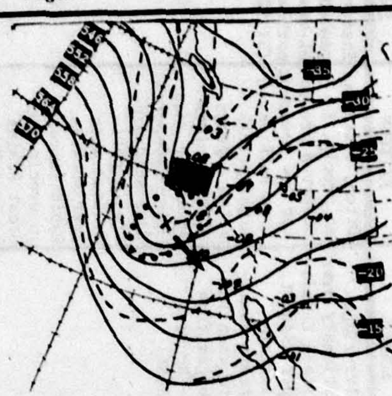


Figure 83: 500mb 12Z 1 Mar 1979

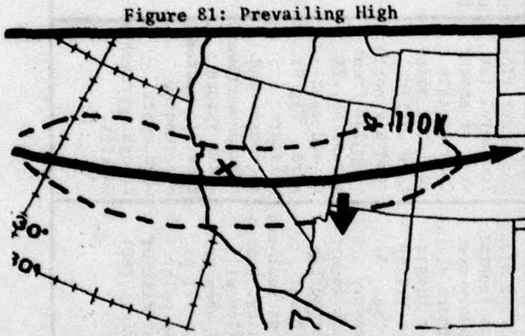


Figure 84: 300mb 12Z 12 Jan 1979

Figure 86: 300mb 00Z 13 Jan 1979

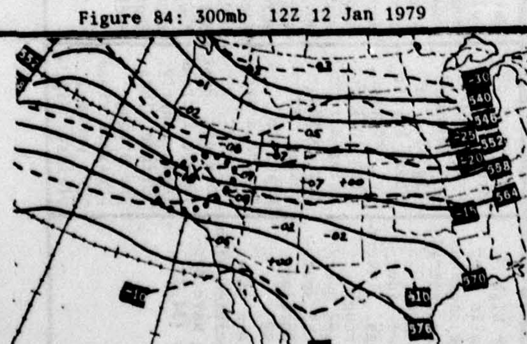


Figure 85: 500mb 12Z 12 Jan 1979

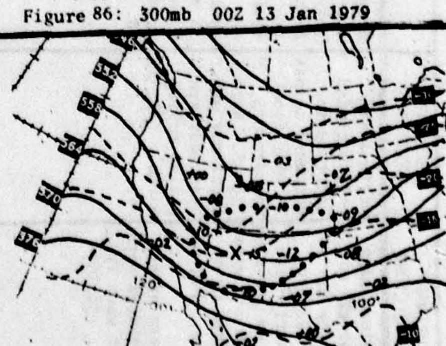


Figure 87: 500mb 00Z 13 Jan 1979

SUMMARY

RECOGNITION OF SYNOPTIC FEATURES FAVORABLE FOR HEAVY SNOWFALL OVER THE GREAT PLAINS (Figures 80 and 81)

SURFACE/LOWER LEVELS

	PRIMARY ANTICYCLONE	PRIMARY FRONT(S)	PRIMARY LOW	LOW LEVEL FEATURES	COLD AIR SOURCE	PRECIPITATION PATTERN	PROBABLE HEAVY SNOW AREAS	WARNING
RECEDING HIGH	Migratory high (mP or cP) moves over the eastern U.S. Return southerly flow sets up lee-side trough and warming over Great Plains. Fig 88 Pattern often associated with short wave systems. (34,35, 36).	North-south cold/occluded front moving eastward across Rockies from western U.S. Fig 88. Warm front may exist over southern plains moving north. (34,35, 36)	Develops within lee-side trough (may or may not be along mP front) over eastern CO or NM. Low eventually moves SE when capture by approaching upper low. Fig 88.	South-north flow. Low-level jet develops and strengthens 12-24 hrs prior to upper low's arrival over Rockies. 35-55 kt jet core across northern TX and cent OK. Rapid flow of gulf moisture along jet from TX to KS-MO. Fig 91	Polar ridge stationary over western Canada-upper Midwest. Polar air streams southward when low emerges from the Rockies (33,34)	Often, little or no precip. is observed preceding low movement from Rockies. Light precip often appears within colder polar air over upper Midwest. Some sctd precip in post-frontal area over Rockies. Rapid increase in precip over Great Plains during/after system recurvature. (72,73)	Eastern CO-TX panhandle-central OK-western MO and northward. Fig 80 (51,52)	mP or cP fronts that "hang up" over the Midwest (Fig 93) are clues that the associated short wave is undergoing deepening and probable upper level cyclogenesis. Look for surface lingering lows west of Rockies. Rapid and intense storm systems may suddenly develop along stationary frontal systems. Figs 93 and 94 (58-64)
PREVAILING HIGH	Polar high prevails over large sections of the central and upper U.S. No lee-side trough. Inverted trough appears over/ west of southern Rockies. Fig 89. Pattern often associated with long wave systems (34,35).	East-west cP stnry front across NM-TX and eastward. Fig 89. If above hasn't yet occurred, then look for polar air pushing southward towards TX prior to trough's arrival over Rockies. Best clues: increasing northerly surface winds and strong pressure rises over central plains. Fig 90	Develops along polar frontal boundary over southern plains-lower Mississippi Valley and Swd. A secondary low within inverted troughing may exist across southern Rockies. Troughing/low will fill when main low develops along polar front east of Rockies. (60)	East-west flow. Low-level jet weak or absent. Considerable residual moisture within cold air north of polar front across NM, TX OK and eastward. Fig 92. Moisture increases and spreads northward under return flow. Increased overrunning when upper trough approaches Rockies.	Cold polar air exists east of Rockies.	Begins along and north of polar front. Precip type depends on strength of cold air. Upslope snow occurs across western plains and Rockies. Precip increases gradually over large areas of the Midwest as the upper trough approaches the Rockies. (75)	Depends on strength and coldness of polar air mass. If cold, heavy snow may occur over a large area from NM-northern TX and northward - Look for transition belt of freezing precip across southern plains-lower Mississippi Valley. Fig 81.	A large area of snow falling across the southern plains may not move northward if short wave moving into southern Rockies continues eastward towards Mississippi Valley. Heavy snowfall will occur south of KS and MO.

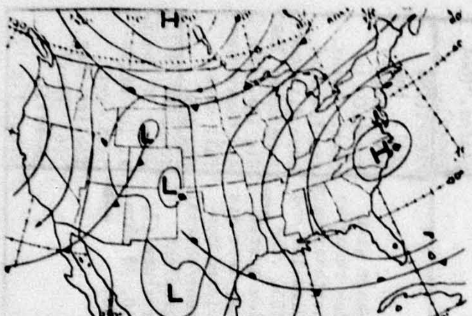


Figure 88: Receding High

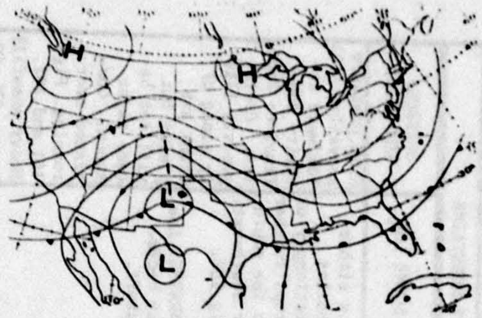


Figure 89: Prevailing High

Figure 90: Prevailing High

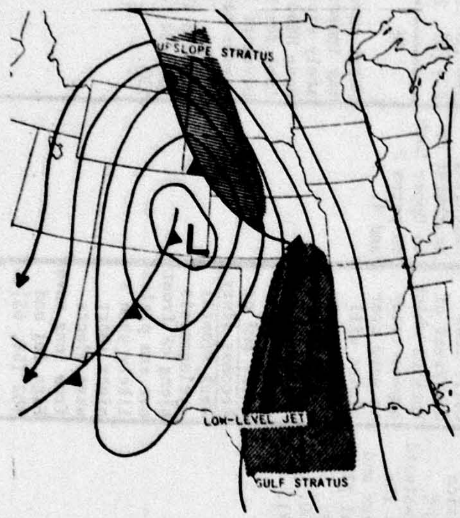


Figure 91: Moisture Pattern, Receding High

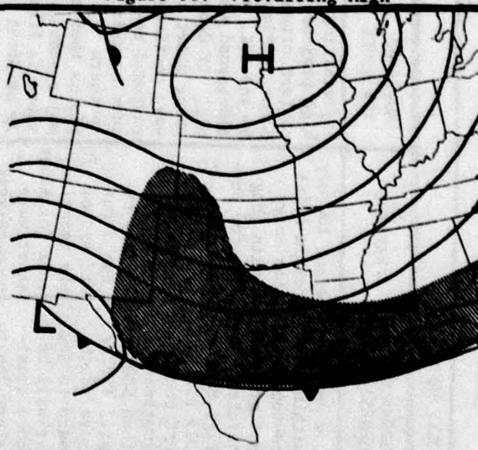


Figure 92: Moisture Pattern, Prevailing High

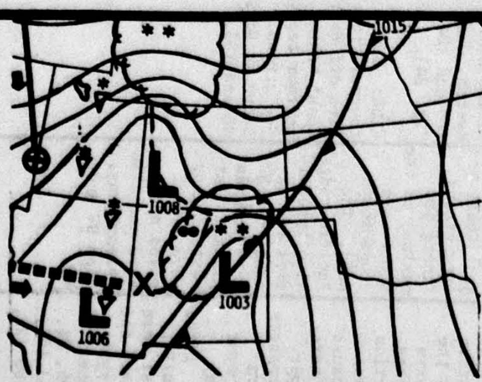


Figure 93: 00Z 19 Nov 1975

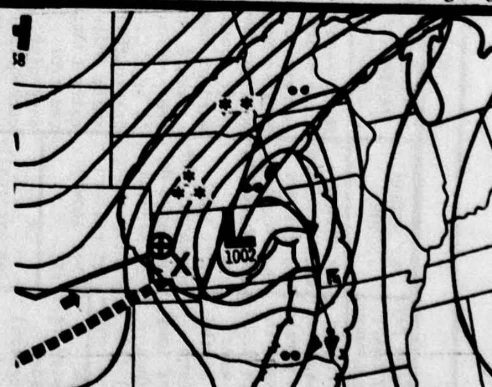


Figure 94: 00Z 20 Nov 1975

SUMMARY

RECOGNITION OF TIME-PHASED SYNOPTIC FEATURES FAVORING HEAVY SNOWFALL OVER THE ROCKY MOUNTAINS/GREAT PLAINS
SHORT WAVES SYSTEMS MOVING THROUGH LONG WAVE TROUGHS

WEST OF ROCKY MOUNTAINS						OVER/EAST OF ROCKY MOUNTAINS			
UPPER FLOW PATTERN AT ONSET OF DEVELOPMENT	JET STREAM (300MB)	500MB HFC * MOVEMENT/ TENDENCY	500MB CYCLOGENESIS AREA	WARNING	SURFACE/ LOW LEVEL	JET STREAM (300MB)	500MB HFC * MOVEMENT/ TENDENCY	500MB LOW	SURFACE/ LOW LEVEL
Identifiable N-S long wave trough persisting over the western U.S. Short wave moves southward into base of long wave (not shown) (18-22). OR Long wave retrogrades from central U.S. and re-establishes itself over the western U.S. as the short wave approaches. This action bears watching because of the various upper level changes in storm development that may occur. Often difficult to forecast when and where the storm system will move. Figs 96, 98, 100 and 103, 104, 105 (23, 24).	Jet stream well-developed and follows the long wave trough configuration. Short wave movements thru long wave do not significantly change jet pattern. (Not shown) (3). OR Jet eventually aligns N-S along/over West Coast and strengthens (incrg jet maxima) as the short wave drops southward. The Pacific ridge also intensifies and extends northward towards Alaska. Jet east of long wave trough moves northward and also strengthens. Figs 97 and 99.	Short wave HFC moves southeastward over Pacific Northwest but may shift southward or southwestward from the previous 12 hr HFC. The southward shift indicates continued trof deepening; consequently, little eastward movement of the storm system. Figs 100 and 104. (23, 24). CLUE: 500mb thermal trough lies off West Coast behind contour trough See arrows shown in Figs 96 and 103.	Low develops within wide contour/thermal gradient (hatched area) Figs 98 and 103 (5,6). If HFC continues southward then 500mb low will either move southward to SWwd or will become quasi-stnry due to continued trough deepening. Continued digging will likely delay eastward movement or further development of associated surface storm west of Rockies. Figs 101 and 102. (10,23,24)	Upper low may remain quasi-stationary within long wave for several days before moving eastward. (20,21,22). Low may become a cut-off system. In the meantime, look for minor short wave troughs (weak HFC's) moving eastward over Arizona and New Mexico shifting northeastward across the southern and central plain states. Fig 100. (18,19).	A prevailing high pressure pattern often occurs. Figs 89 and 101. Widespread precip. If deepening short wave continues eastward recurving over southern plains then a major snowstorm is likely on Great Plains. Not shown. (65 thru 69). However, lows over/west of Rockies which appear ready to move over plains will remain stnry and fill when the associated upper low moves Swd or becomes stnry. Weak frontal cyclogenesis along cP front ovr srn plains likely when a minor short wave ejects from long wave. Figs 101 and 102 (58, 65).	Increasing amplitude and strengthening of jet. Strong max appears within base of long wave and subsequently moves northeastward along jet axis east of trough axis. Fig 97 and 99. (3) WARNING: See "Wing Maxima Appearing Southwest of an Upper Low" on pages 3 and 4.	One of two events will occur: Height falls may linger and decrease within base of long wave over southwestern U.S. Indicates short wave has decreased in intensity. Several days may pass before increased short wave activity → occurs. Fig 100 (20 thru 22) (25, 26). OR Short wave may immediately eject and move NEwd. Look for HFC movement NEwd across central plains. Figs 105 and 108. (23, 24, 26, 27). →	Low either remains stationary or drops further to the south or southwest. Fig 100. WARNING: Low may become cutoff. → Short wave low recurves northeastward. Figs 104 and 105. The → low system may lose its closed contour/thermal gradient feature (7, 10, 18 thru 24). →	High pressure prevails. (81) low/wave activity confined to Rockies. Cyclogenesis likely along cP front srn plains but will not become major storm. Continued over running. Figs 101 and 102. Heavy snowfall area: NM, CO, WY, and extreme western plains. (Not shown). PREVAILING (81): Low dvlps alg cP front CO to cntrl plains. Sfc low lctd some distance from upper low. Fig 108. (58, 63) Heavy snowfall area: Fig 109. RECEDING (81): mP or cP frontal low organizes over Rockies. Fig 106. Heavy snowfall area: Fig 107.

See pages 81 and 82 for surface and low level features. * HFC - 500mb height fall center.

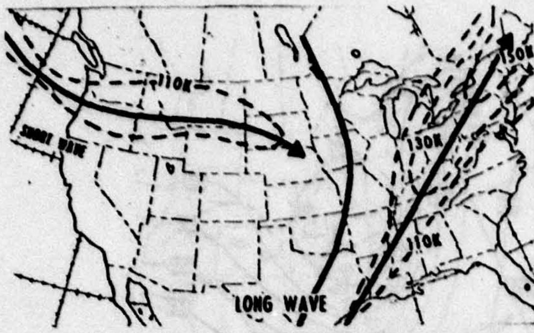


Figure 95: 300mb 00Z 5 Dec 1978

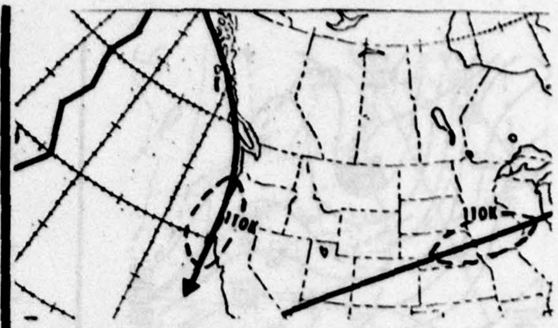


Figure 97: 300mb 00Z 6 Dec 1978

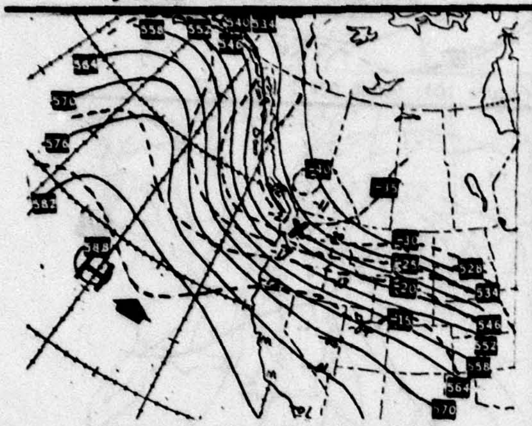


Figure 96: 500mb 00Z 5 Dec 1978

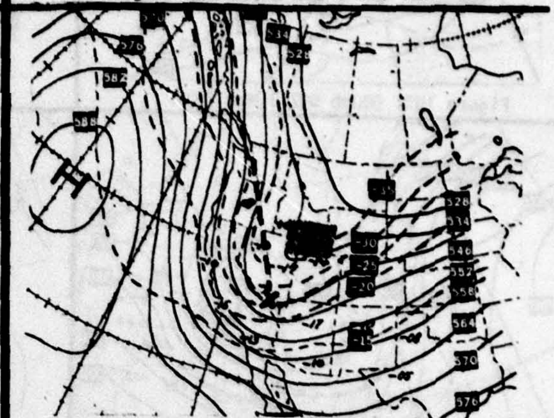


Figure 98: 500mb 00Z 6 Dec 1978

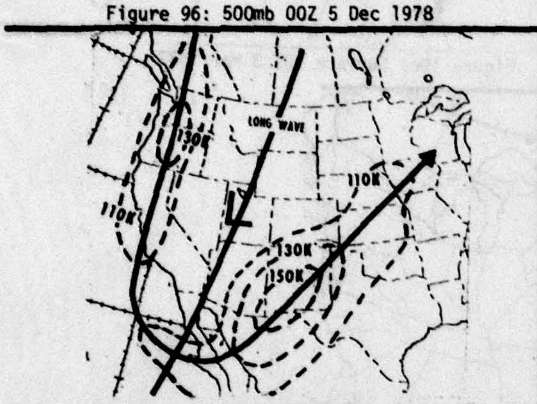


Figure 99: 300mb 00Z 7 Dec 1978

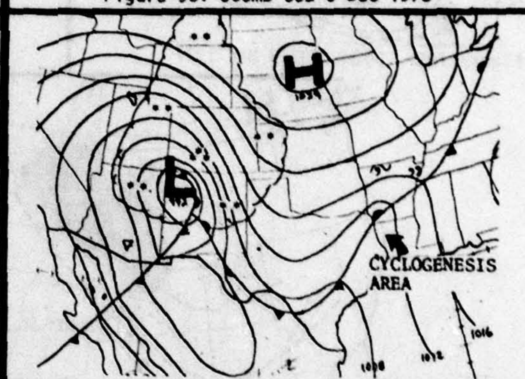


Figure 101: Surface 00Z 7 Dec 1978

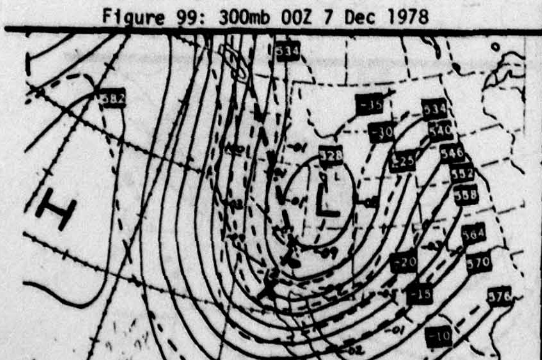


Figure 100: 500mb 00Z 7 Dec 1978

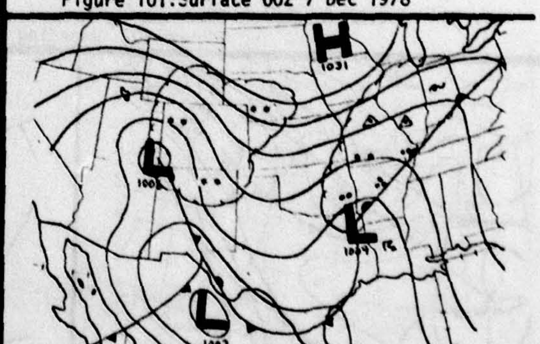


Figure 102: Surface 06Z 7 Dec 1978

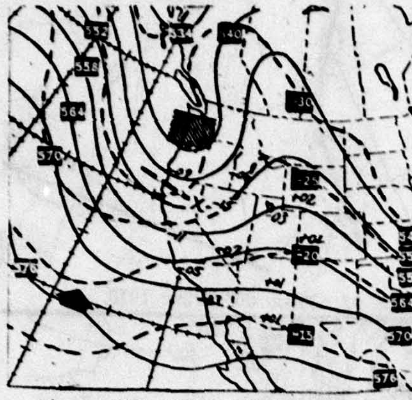


Figure 103: 500mb 00Z 1 Mar 1977

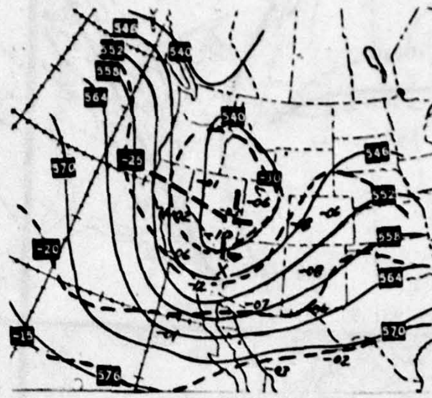


Figure 104: 500mb 00Z 2 Mar 1977

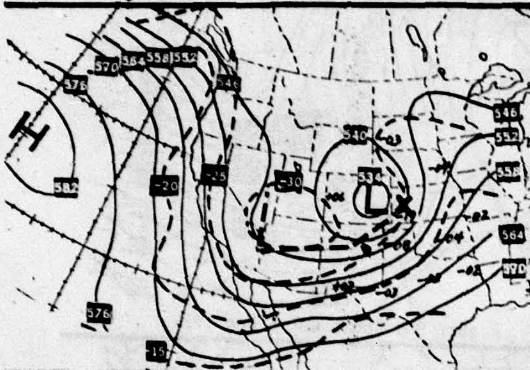


Figure 105: 500mb 00Z 3 Mar 1977

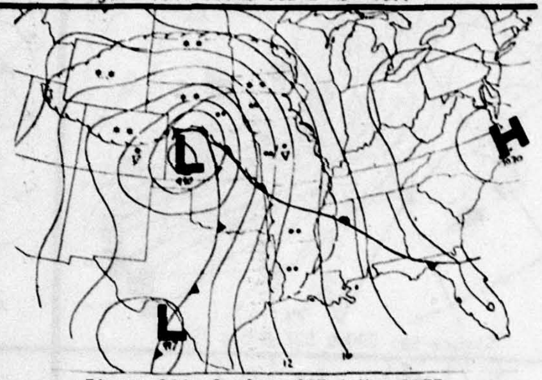


Figure 106: Surface 00Z 3 Mar 1977

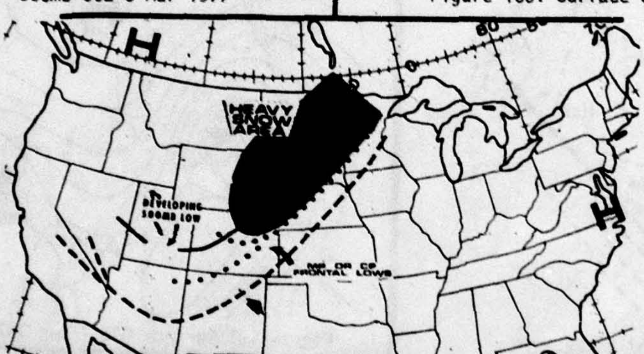


Figure 107: Receding High

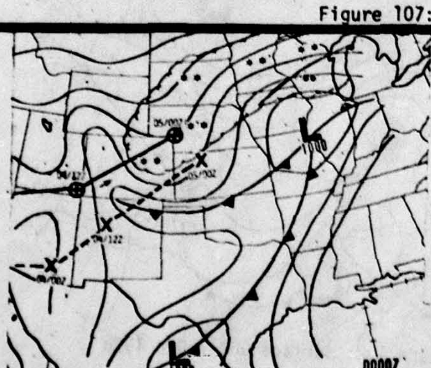


Figure 108: Surface 00Z 5 Mar 1976

Figure 109: Prevailing High

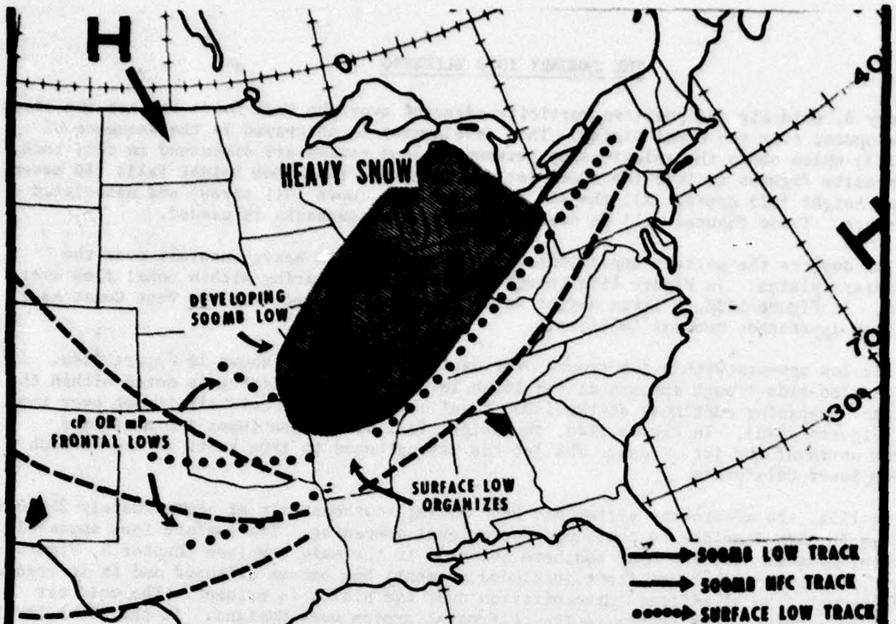


Figure 110: Receding High

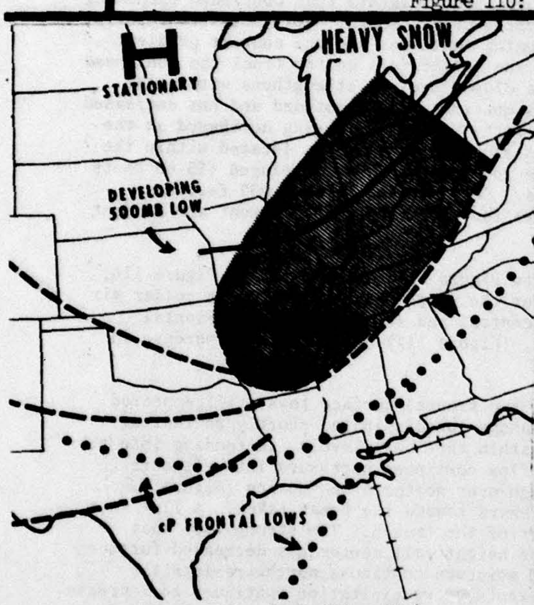
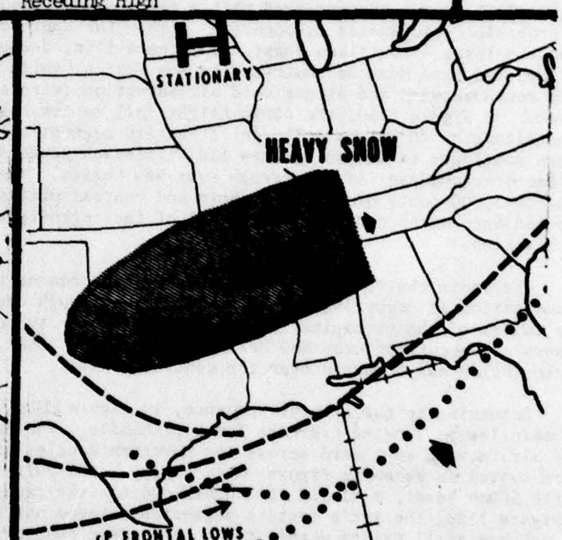


Figure 111: Prevailing High



Note: The southern edge of the heavy snow area depicted will expand southward towards the 500mb HFC track in proportion to the coldness of the prevailing air mass.

Figure 112: Prevailing High

Shown above (Figures 110 through 112) are three more examples of the relationships between the tracks of the 500mb low, the 500mb height fall center and the surface low described in Chapter 5. Many variations of the relationships shown may occur; forecasters should determine where and when recurvative of the upper system will take place. Also, considerations of where the primary surface anticyclone will lie (and its air mass characteristics) - whether it is receding from or will prevail over the Midwest - are necessary to determine heavy snowfall areas. Don't become confused with the current surface pattern where, perhaps, two or more surface frontal lows are occurring during storm organization. The primary low will develop and intensify rapidly within the vicinity of upper level recurvature (bottoming out) areas.

EXAMPLES OF HEAVY SNOWFALL PATTERNS

THE JANUARY 1975 BLIZZARD

On January 8, cold air and positive vorticity advected over the West Coast and set the stage for storm development over the Great Plains. This development is portrayed in the sequence of figures (113-123) which shows the relationship between various parameters discussed in this tech note. The composite figures include the 300mb jet and isotachs, the 500mb height falls (50 meter increments) and height fall center (X), the low level jet axis (open tail arrow) and associated low-level moisture. These figures will be discussed only where emphasis is needed.

Figure 113 depicts the pattern approximately 36 hours prior to heavy snowfall over the central and western plains. In Figure 113c trough deepening is appearing within zonal flow over the West Coast. In Figure 113d, a large height falls area has appeared over the West Coast as a strong jet stream approaches central California.

A lee-side low appears within the trough over eastern Colorado as shown in Figure 114a. In Figure 114b, the lee-side trough appears at the 850mb level. Thermal ridging is noted within the lee-side trough. Deepening continues at the 500mb level evident by the cold air trough over the western U.S. (Figures 114c). In Figure 114d, the height fall center continues southeastward towards Arizona north of the jet stream. The jet has strengthened to 150+ knots as the isotach area moves into lower California.

In Figure 115a, the mP frontal system had been moving southeasterly at approximately 25 knots, but is beginning to slow down due to continued upper level deepening. Two surface lows appeared along the frontal system. The low over southern Colorado is the main low (see Chapter 5, Figure 47). The northern portion of the mP front (occluded segment) has become diffused and is indicated by an inverted trough. No significant precipitation over the plains is evident. The cold air source for this developing storm system is the cP frontal system over Montana. At the 850mb level (Figure 115b) a low has appeared within the lee-side trough which suggests that continued deepening and probable cyclogenesis is occurring within the approaching upper trough. Gulf moisture appears along the Texas - Louisiana coast. In Figure 115c, deepening continues and the contour gradient has loosened from Montana southward to New Mexico, while the height fall center track has continued to be southeastward and strong cold air advection (with a closed pocket) strengthens within the trough. In Figure 115d, the 500mb height fall center has continued southeastward and has decreased in magnitude by 20 meters. The jet's eastern segment over the Midwest is moving northward as the trough continues to deepen. A new 110 kt isotach appears along the jet and is located within the southeastern quadrant of the trough over New Mexico. The low level jet has developed (55-60 knots at 2,000-3,000 feet) over the southern and central plains. Gulf stratus below 3,000 feet has advected into north central Texas. All of the ingredients for major storm development are evident at this time.

The radar charts (Figures 116 and 117) subsequent to Figure 115 are shown. In Figure 116, precipitation is occurring within the inverted trough over the upper Midwest and in the colder air over Colorado. No precipitation has developed over the central and southern plains. Frontal showers are occurring over New Mexico. Five hours later, (Figure 117) a significant increase in precipitation has occurred over the central plains.

Returning to the 12-hour sequence, in Figure 118a, two frontal surface lows still appeared. The main low is located over the Texas panhandle. The Kansas low dissipated shortly thereafter. Cold air, moving southward across the northern Rockies within the lower levels, is feeding into the storm system as shown in Figure 118b. Warm, moist gulf flow continues northward into Missouri. At the 500mb level, a closed low appears within the trough over northern New Mexico (Figure 118c). In Figure 118d, the jet's eastern segment has moved northward toward the Great Lakes. A 110+ knot jet maximum still exists within the southeastern quadrant of the trough. The strong 150+ knot jet maximum is still prominent over the western U.S. The height fall center has decreased further as the center bottoms out over eastern New Mexico. Gulf moisture continues northward into the storm system supported by a weakening low level jet (40 knots). Precipitation continues to increase over the Midwest as shown in Figure 119, nearly six hours later. The entire system has bottomed out and is beginning to turn northeasterly. The increasing snow area over western Kansas and the Texas panhandle (associated with the 500mb low) is the area to watch for significant snowfall. As the 500mb low now moves northeastward the snowfall area, likewise, expands and moves northeastward.

In Figure 120a, the main surface low that was located over the Texas panhandle 12 hours ago has moved northeastward to eastern Kansas and has deepened 5 millibars. The storm system has become well organized. Snow has spread into Kansas and Nebraska. The inverted trough north of the low is still persisting; the surface low, now moving northeasterly, should move towards this inverted trough. At the 500mb level, (Figure 120c) intensification continues and the trough now resembles the appearance of a long wave feature. The 500mb low should now turn northeastward. The 300mb jet axis east of the trough has become oriented S-N, conducive to development of a long wave trough pattern. The height fall center is moving northward and has increased in magnitude after decreasing during the previous 12 hours. The strong jet maximum still exists over the

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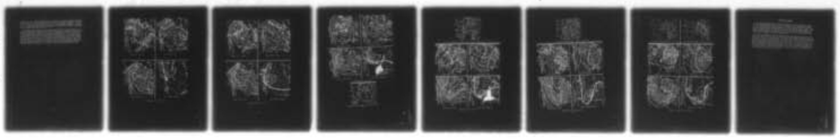

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DDC

western U.S. The storm system is still supported by a maximum isotach area (110+ knots) within the eastern section of the trough from Texas to Minnesota. Figures 121 and 122 depict the precipitation areas at selected times subsequent to Figure 120). The snow area has increased and shows a slow easterly movement. Blizzard conditions are occurring over eastern Nebraska at the time of Figure 121 and were still in effect nine hours later.

The storm system has become fully developed as shown in Figure 123a. The central pressure has dropped 12 millibars during the past twelve-hour period. The 500mb low has moved northeasterly to eastern Nebraska and appears to have become a short wave within a long wave trough pattern (Figure 123c). In Figure 123d, a maximum isotach (130+ knots) jet appears within the trough's bottom over Texas; however, the storm system continues northward supported by the 110+ knot maximum over Illinois and Wisconsin. The persistent jet core with strong isotach areas over the western U.S. throughout the storm system's life most likely caused the system to appear to change from a short wave to a long wave pattern. This storm system continued northward into Minnesota and produced a blizzard from eastern Nebraska and Iowa northward to the eastern Dakotas, Minnesota and Wisconsin.

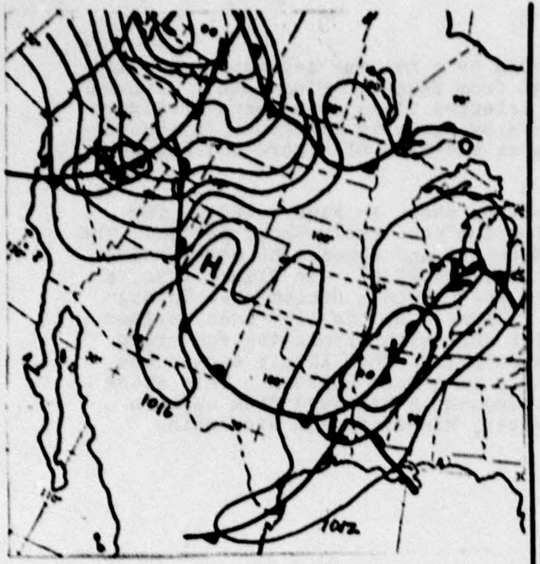

Figure 113a: Surface

Figure 113b: 850mb

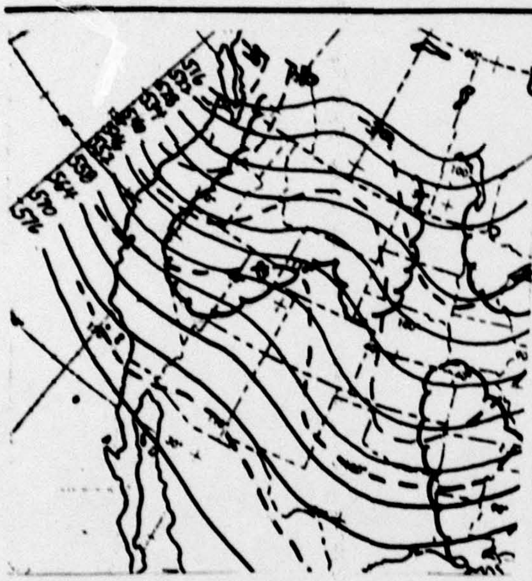

Figure 113c: 500mb

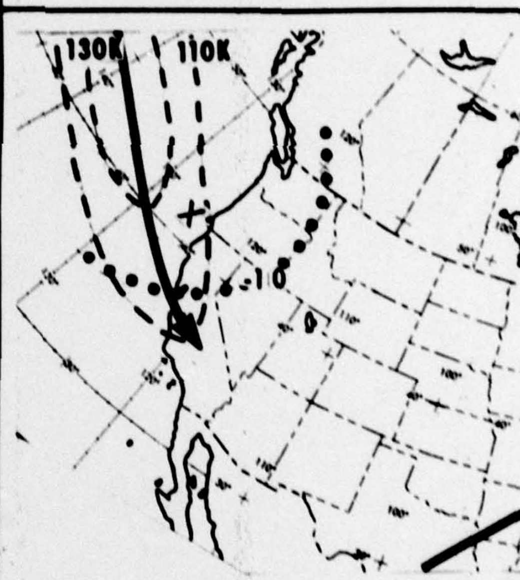

Figure 113d: Composite

FIGURE 113: 12Z 8 JAN 1975

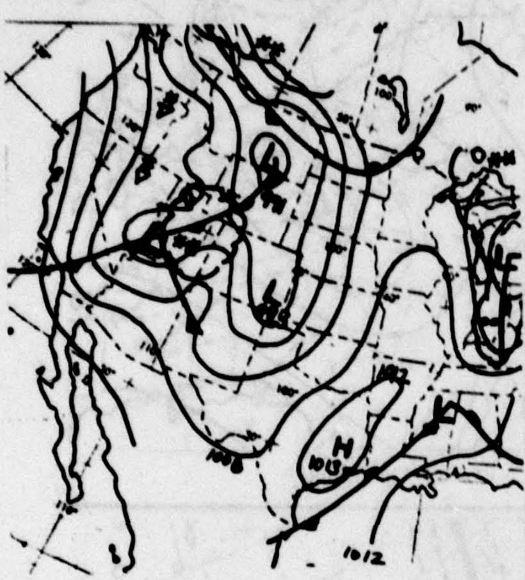

Figure 114a: Surface

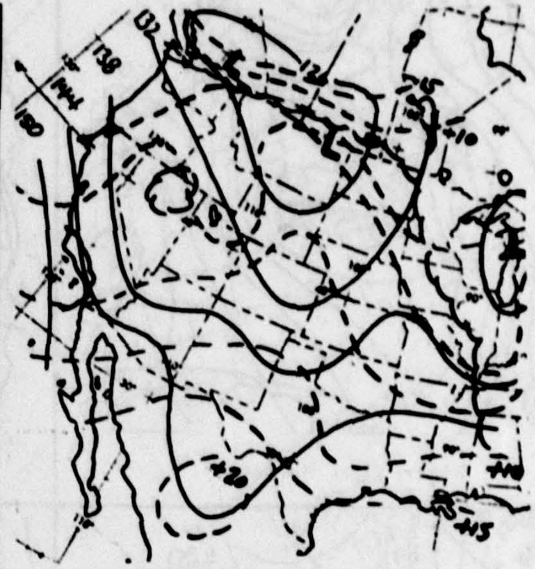

Figure 114b: 850mb

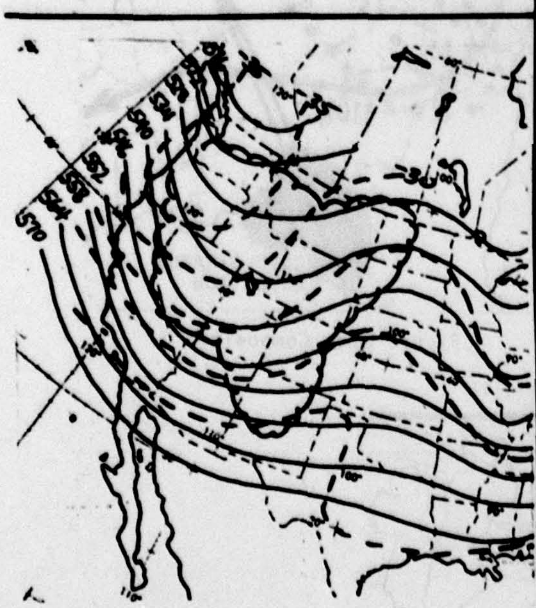

Figure 114c: 500mb

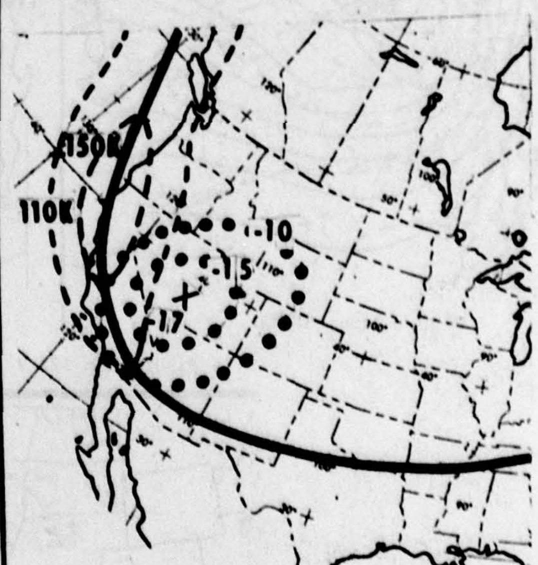

Figure 114d: Composite

FIGURE 114: 00Z 9 JAN 1975

Figure 115a: Surface

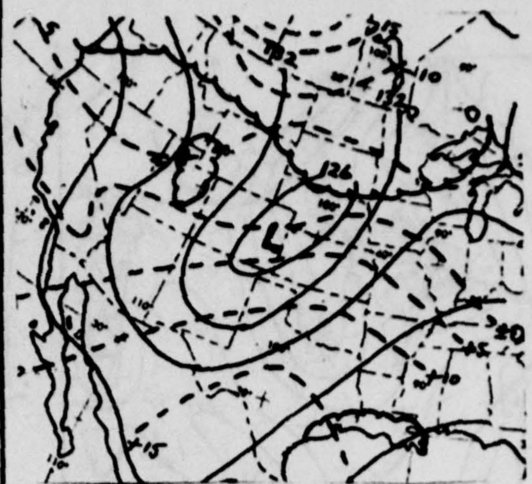

Figure 115b: 850mb

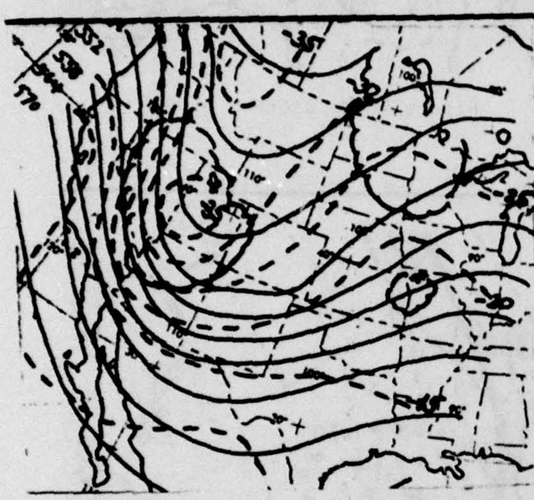

Figure 115c: 500mb

Figure 115d: Composite

Figure 115: 12Z 9 Jan 1975

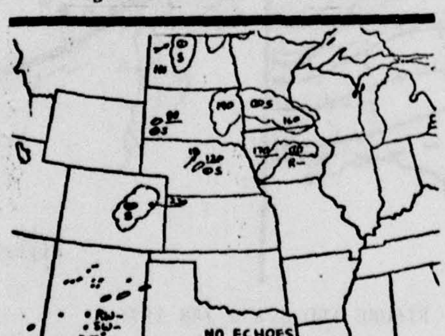

Figure 116: Radar Summary, 1735Z 9 Jan 1975

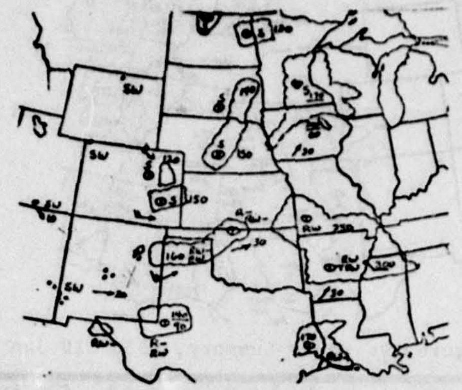

Figure 117: Radar Summary, 2335Z 9 Jan 1975

Figure 118a: Surface

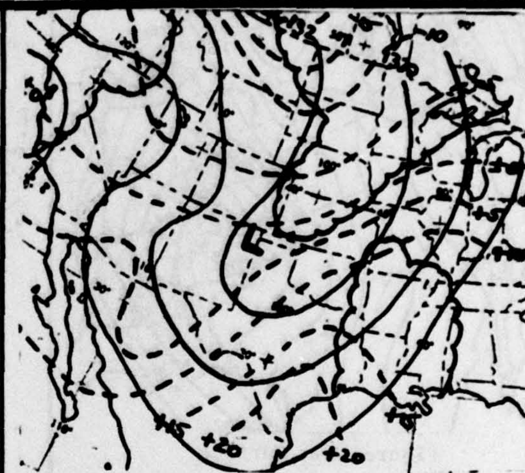

Figure 118b: 850mb

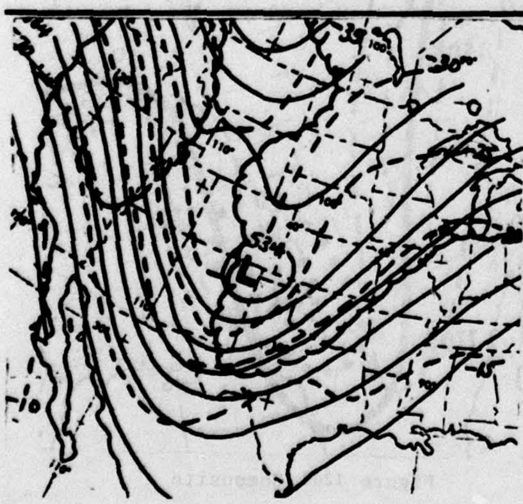

Figure 118c: 500mb

Figure 118d: Composite

FIGURE 118: 00Z 10 JAN 1975

Figure 119: Radar Summary, 0535Z 10 Jan 1975

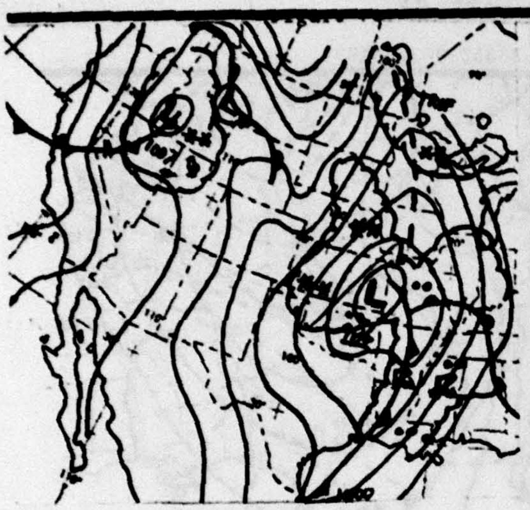

Figure 120a: Surface

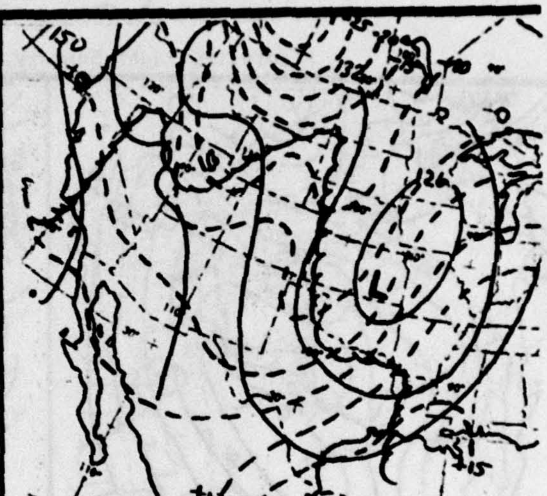

Figure 120b: 850mb

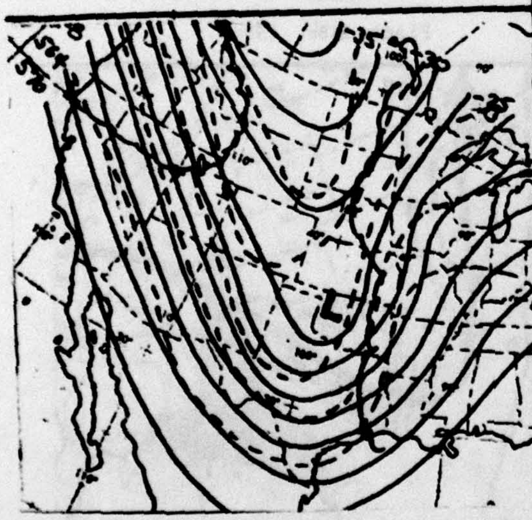

Figure 120c: 500mb

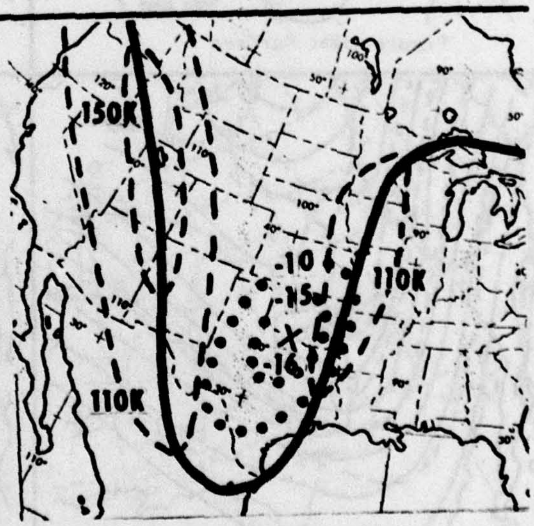

Figure 120d: Composite

FIGURE 120: 12Z 10 JAN 1975

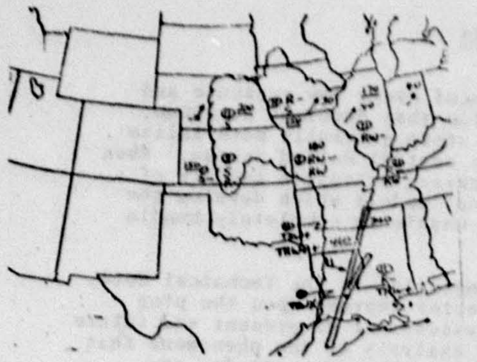

Figure 121: Radar Summary, 1435Z 10 Jan 1975

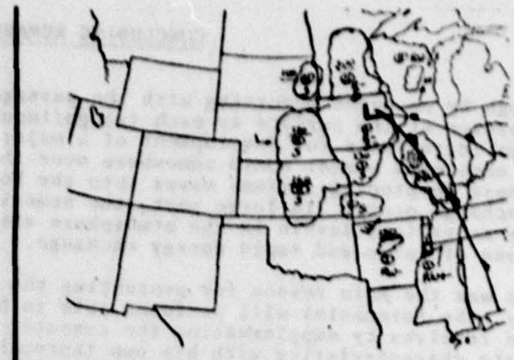

Figure 122: Radar Summary, 2335Z 10 Jan 1975

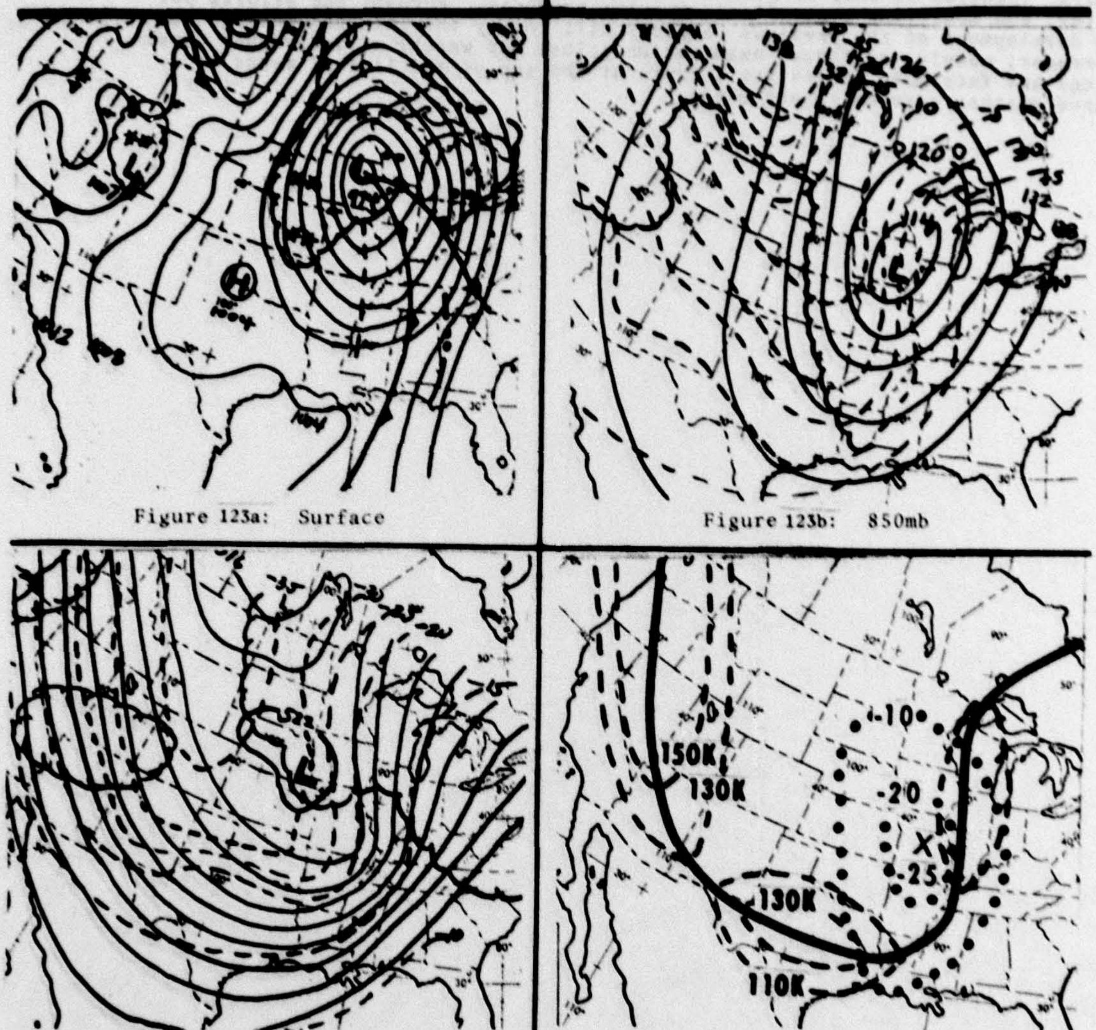

Figure 123a: Surface

Figure 123b: 850mb

Figure 123c: 500mb

Figure 123d: Composite

FIGURE 123: 0000Z, 11 JAN 1975

CONCLUDING REMARKS

Though by no means occurring with the passage of every low pressure and frontal system at the surface or each trough/impulse that develops at 500mb, the proper ingredients for development of a major storm generally materialize at least once each winter month somewhere over the central United States. When one of these developing systems moves into the Rockies, extensive amounts of energy exchange occur. In large part, the numerical models which develop the prognoses at various levels in the atmosphere are unable to completely handle these cases of large and rapid energy exchange.

This was the main reason for presenting the material in the Technical Note. Hopefully, the forecaster will be found able to better improve upon the prog charts he receives by supplementing the computer assessment of present and future atmospheric characteristics with his own thorough analysis of the phenomena that have been offered to him through this Technical Note. The forecast for any specific location is only as good as the efforts of forecasters in using, supplementing, and modifying centralized computer products. Perhaps the efforts put into development of the previous chapters will convey the intended message to the reader; namely, continual examination (close met watch) of individual observations and facsimile charts still ranks at the top of the list of means to enhance weather service to our users.